Ongoing meteor work

The VMO file format. I. Reduced camera meteor and orbit data

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We propose a standard XML-based file format for storing and transferring reduced data from photographic and video meteor observations and meteoroid orbits and trajectories. The format is the result of discussions within the Virtual Meteor Observatory (VMO) team, which aims to facilitate collaboration in the meteor science community and increase the scientific impact of combined observational data. The proposed format is extensible and allows meteoroid orbits and trajectories to be traced back to the original observing data and algorithms. We provide a description of the structure of the format and give precise definitions for each data field.

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1 Introduction

The Virtual Meteor Observatory (VMO) project aims to facilitate collaboration between different meteor groups, by giving meteor researchers an easy way to query and retrieve data available to the worldwide community. During the first meeting of the VMO team, it was agreed that a first step towards this goal is to specify a standard file format to store and exchange meteor data (Barentsen et al., 2007; Koschny et al., 2009). The format should store data that has been *reduced* to a form that makes it suitable for scientific use, yet provide sufficient technical details to allow the quality and origin of the observation to be assessed. Such a format would allow existing data archives and software tools to become compatible through single format conversion tools. It would also encourage software to support a standard format and allow observations to be stored in centralized and searchable archives.

The architecture of the VMO was discussed previously and the reader is referred to Koschny et al. (2008) for a description. In this paper, we propose a file format for storing the reduced results from photographic and video-based observations (hereafter collectively referred to as "camera observations"). We also specify how to store meteoroid trajectories and orbits (which may be derived from any observing technique). In a follow-up article in WGN, we will extend the format to visual observations and fireball reports. By then, we will have covered almost all data sections proposed by Koschny et al. (2009), with the exception of observations by forward or backward scatter radio techniques. Formats for forward scatter data are available from Brentjens (2006) and Terrier (2009) and may be incorporated in the future.

The format presented here, "VMO Format 1.0", is also documented on the website of the International Meteor Organization, `http://vmo.imo.net/standards`, where it is accompanied by additional examples and validation tools. We recommend users to check the website for updates.

2 File structure

The VMO file format is based on XML, which is a standard method for storing complex information in simple text files. An XML file is a hierarchical structure of *elements*, which are strings of data enclosed by start- and end-tags. For example, a Perseid meteor of magnitude +2.5 seen on 2009 August 12 may be formatted using XML as follows:

```
<meteor>
  <time>2009-08-12T00:04:13.25</time>
  <shower_code>PER</shower_code>
  <mag>2.5</mag>
</meteor>
```

An example of a well-known XML-based format is XHTML, which is used to define the layout of webpages using elements such as `<title>` and `<img>`. In this paper, we describe the VMO format by defining our own suitable elements. These elements must be used according to the XML syntax rules, which are not given here but can easily be retrieved online[1].

A file in the VMO format starts with the `<vmo>` root element, which appears exactly once and encloses the entire contents of the file. The root element must specify the version number (1.0) and the organization that defined the format (IMO) as follows: `<vmo version="1.0" xmlns="http://www.imo.net">`. The root element may have certain child elements such as `<location>` (defining an observing site) and `<cam_session>` (a camera observing session). These child elements may appear an unlimited number of times in any order. Some of the elements refer to each other, for example a camera observing session refers to an observer and a location as follows:

```
<vmo version="1.0" xmlns="http://www.imo.net">
   <location>
      <location_code>DEPOTS</location_code>
      <name>Potsdam</name>
```

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IMO bibcode WGN-381-barentsen-vmo-camera
NASA-ADS bibcode 2010JIMO...38...10B

[1]`http://www.w3schools.com/xml`

```
    ...
  </location>

  <observer>
    <observer_code>ARLRA</observer_code>
    <first_name>Rainer</first_name>
    <last_name>Arlt</last_name>
    ...
  </observer>

  <cam_session>
    <location_code>DEPOTS</location_code>
    <observer_code>ARLRA</observer_code>
    ...
  </cam_session>
</vmo>
```

A precise definition of the various elements and their relations is given in Tables 1–13. A graph of the structure is shown in Figure 1, an example file is shown in Figure 2.

Note that we introduce sessions which are comprised of smaller observing periods. Such sessions are not necessary for the complete and unambiguous storage of data, but the grouping into sessions makes the handling of data packages far more comfortable. Typical sessions may correspond to nights, but can also correspond to group campaigns or other practical entities. All photographic, video, and later on also visual observations will be grouped in sessions.

The tables and graph show the allowed multiplicity (occurence) of each element. The possible values are "1" if the element is obligatory, "0..1" if the element is optional but should not appear more than once, "0..N" if the element is optional and can appear several times, and "1..N" if the element is obligatory and can appear several times. Elements may appear in any order.

Most elements are intentionally left optional to allow the format to be used even when only minimal data is available. This allows the format to be useful for older data which was created before any standard was defined, or even historical data. However, one should make a reasonable effort to include as many elements as possible.

3 Conventions

In addition to the element definitions given in the tables, a VMO file must adhere to the following conventions:

1. The number of digits used to store a number must always be *at least* 1 or 2 larger than would be called for by the "significant-figures rule". For example, if an eccentricity was determined to be 0.3266, but with an uncertainty of 0.0021, one should retain the precision of $e = 0.3266 \pm 0.0021$ and *not* round to $e = 0.327 \pm 0.002$. The "significant-figures rule" should *not* be used when storing numbers that may be used in further computations, because it introduces rounding errors.

2. Uncertainties must be given as a standard error (σ) or covariance value. These errors must be obtained by propagating the uncertainties of the input data (e.g., the meteor astrometry) to the output data (e.g., the orbital elements). This may be done using analytical propagation formulas or statistical Monte Carlo iterations.

3. All equatorial coordinates must be given in decimal degrees (epoch J2000.0). At least 5 digits behind the decimal sign must be supplied if arcsecond-precision is available.

4. All times must be given in Coordinated Universal Time (UTC). This is the international standard on which civil time is based, with leap seconds added at irregular intervals. Times must be formatted using the ISO 8601 standard (e.g., "2009-08-12T23:14:05").

4 Traceability

During discussions on the VMO format, several meteor scientists emphasized the importance of being able to trace reduced data back to the original observations and processing steps (Koschny et al., 2007). For example, it should be possible to retrieve the original single-station data that was used to compute an orbit. It should also be possible to determine which algorithms and processing steps were used in the computations. The VMO format allows such traceability in the following ways:

1. Orbits and trajectories may be linked to the original single-station data by means of a <meteor_code> element (cf. Figure 1). These unique meteor codes may be assigned using the rules given in Table 7.

2. Orbits refer to an <orbit_pipeline> element (cf. Table 9), which holds references and descriptions of the various processing steps and algorithms used in the determination of the trajectory and orbit. In addition, the state vector of the meteor can be stored to allow the orbit to be recomputed easily.

3. The format provides a <file> element (cf. Table 13), which allows raw and intermediate data to be linked to the reduced data. For example, we may link an original video clip to a meteor as follows:

```
<vmo version="1.0" xmlns="http://www.imo.net">
  ...
  <meteor>
    <shower_code>PER</shower_code>
    <mag>2.5</mag>
    <file>
      <path>videos/met293.avi</path>
      <comments>
        Meteor of 2009 Aug 12, 23:14:05
      </comments>
    </file>
  </meteor>
  ...
</vmo>
```

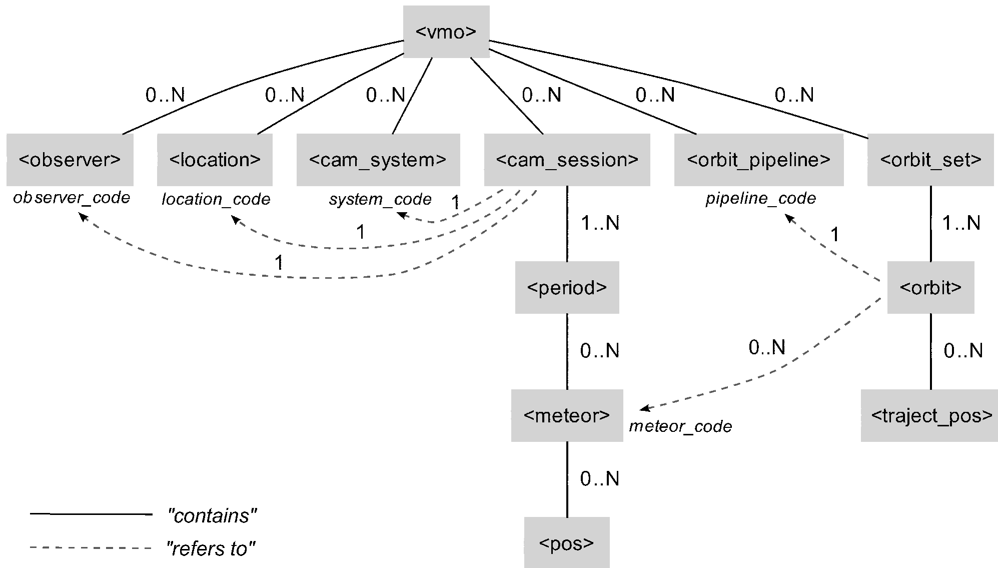

Figure 1 – Structure of the most important elements in the VMO format. Solid lines denote an element containing another element, dashed arrows denote an element referring to another element through a unique code. Numbers next to the arrows denote the minimum and maximum multiplicity of the relation. All the elements are defined in detail in Tables 1–13.

```
<?xml version="1.0" encoding="UTF-8"?>

<!-- VMO Format example for video observation -->
<vmo version="1.0" xmlns="http://www.imo.net">

  <observer>
    <observer_code>KOSDE</observer_code>
    <first_name>Detlef</first_name>
    <last_name>Koschny</last_name>
    <city>Noordwijkerhout</city>
    <country_code>Netherlands</country_code>
    <email>Detlef.Koschny@esa.int</email>
  </observer>

  <location>
    <location_code>NLNOOR</location_code>
    <name>Noordwijkerhout</name>
    <country_code>NL</country_code>
    <lon>4.491112</lon>
    <lat>52.265282</lat>
    <height>55</height>
  </location>

  <cam_system>
    <system_code>TEC1</system_code>
    <name>TEC1 system, ESA/RSSD</name>
    <system_type>VIDEO</system_type>
    <contact_code>KOSDE</contact_code>
  </cam_system>

  <cam_session>
    <system_code>TEC1</system_code>
    <location_code>NLNOOR</location_code>
    <observer_code>KOSDE</observer_code>
    <software_code>METREC_V4.1+</software_code>
    <camera_code>WATEC</camera_code>
    <lens_code>FUJ50_1.2</lens_code>
    <gain>highest setting</gain>

    <period>
      <start>2009-01-30T18:04:40</start>
      <stop>2009-01-31T05:00:00</stop>
      <teff>10.9175</teff>

      <meteor>
        <meteor_code>CAM-20090130-TEC1-M001</meteor_code>
        <time>2009-01-30T18:17:21.69</time>
        <shower_code>SPO</shower_code>
        <speed>14.9</speed>
        <mag>2.04</mag>
        <e_mag>0.42</e_mag>

        <pos>
          <pos_no>1</pos_no>
          <time>2009-01-30T18:17:21.69</time>
          <mag>2.63</mag>
          <pos_ra>110.91751</pos_ra>
          <pos_dec>72.38500</pos_dec>
          <e_mag>0.42</mag>
          <e_pos_ra>0.0321</e_pos_ra>
          <e_pos_dec>0.0321</e_pos_dec>
        </pos>

        <pos>
          <pos_no>2</pos_no>
          <time>2009-01-30T18:17:21.74</time>
          <mag>2.54</mag>
          <pos_ra>110.01901</pos_ra>
          <pos_dec>72.09010</pos_dec>
          <e_mag>0.42</e_mag>
          <e_pos_ra>0.0321</e_pos_ra>
          <e_pos_dec>0.0321</e_pos_dec>
        </pos>

        ...

      </meteor>
    </period>
  </cam_session>
</vmo>
```

Figure 2 – Example of a video meteor in the VMO format. Note that the right column of this figure needs to be stored below the left column in a real file.

This mechanism allows observing software to use the VMO format as the main output format for the reduced data, while keeping the raw and intermediate data in the software-specific formats. Data archives may decide whether or not to store this raw data centrally, depending on the available storage and bandwidth resources. There is a <file> option for most of the tables. The <orbit_pipeline> can be accompanied by actual reference papers or even entire software packages using the <file> element.

5 Extending the format

The VMO format is designed to store reduced data, e.g. astrometric and photometric measurements, which are ready to use for scientific analyses. In addition to these parameters, observations produce a lot of raw and intermediate data. We have chosen not to include most of such data, either because it would make the format needlessly complex or because there is no standard way to store the information.

However, the XML syntax provides a mechanism to include additional data in an existing format by means of adding custom elements. Any user may add his own elements by using a *namespace prefix* in the element names. These elements marked in that way are now outside the namespace of the VMO, `http://www.imo.net`. For example, the Polish Fireball Network (PFN) decided to include the list of astrometric reference stars in the VMO files. This is achieved by adding a prefix, "pfn", in front of their custom elements, and the namespace `http://pfn.pkim.pl`. For example:

```
<vmo version="1.0" xmlns="http://www.imo.net">
  ...
  <pfn:refstar xmlns:pfn="http://pfn.pkim.org">
    <pfn:x>0.2486</pfn:x>
    <pfn:y>0.3654</pfn:y>
    <pfn:ra>12.574894</pfn:ra>
    <pfn:dec>36.542478</pfn:dec>
  </pfn:refstar>
  ...
</vmo>
```

It is likely that the extension to store reference star data will be included in the next version of the VMO format, after some additional discussions in the VMO team. Other future extensions may include support for spectra and moving locations (i.e., describing the path of an aircraft). We invite anyone using extensions to join the VMO team and help improve the standard.

We refer the reader to the XML syntax rules for further details on adding custom elements[2].

6 Conclusion

We presented the first version of an extensible XML-based file format for reduced data from video- and photographic meteor observations and meteoroid orbits and trajectories. An initial database implementation is now available at `http://vmo.imo.net` which brings all these tables (and additional auxiliary ones) together in a relational database with some software tools for data ingestion and analysis. These software tools are also available as services to outside users. Data providers will have to provide ingestion routines which convert the data to the VMO format as described in this paper.

We invite the community to evaluate the format and propose corrections and extensions. Meteor researchers are also invited to contribute with actual datasets to let the VMO grow and to discover possible short-comings of the data model described here. Updated versions of the format will be published on the IMO website.

[2] `http://www.w3schools.com/xml/xml_namespaces.asp`

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```
<?xml version="1.0" encoding="UTF-8"?>

<!-- Example orbit / trajectory -->
<vmo version="1.0" xmlns="http://www.imo.net">

 <orbit_pipeline>
   <pipeline_code>UFO2.21</pipeline_code>
   <name>UFOOrbit 2.21 by SonotaCo</name>
   <astrometry>Uses UFOAnalyzer 2.25 by SonotaCo</astrometry>
   <trajectory>Ceplecha (1987)</trajectory>
   <errors>Uncertainties propagated by Monte-Carlo</errors>
 </orbit_pipeline>

 <orbit_set>
   <set_code>ORB-ARLRA-PER2009</set_code>
   <contact_code>ARLRA</contact_code>
   <version>2009-06-12T18:00:00</version>

   <orbit>
     <pipeline_code>UFO2.21</pipeline_code>
     <orbit_type>VIDEO</orbit_type>
     <time>2007-08-13T00:16:06.015</time>
     <shower_code>PER</shower_code>
     <iau_no>0007</iau_no>

     <!-- Orbital elements -->
     <q>0.959751</q>
     <aph>15.732</aph>
     <a>8.346</a>
     <e>0.8850</e>
     <i>112.997</i>
     <omega>152.542</omega>
     <asc_node>139.803842714</asc_node>
     <t0>240220518.531</t0>
     <m0>0.801</m0>

     <!-- State vector from which orbit can be computed -->
     <state>
       2007-08-13T00:16:06.015,6786436.2,
       356741.9,123474.3,35425.6,12325.4,23747.2
     </state>

     <!-- Brightness, mass, velocity, radiant -->
     <mag_abs>1.21</mag_abs>
     <mass>0.0821</mass>
     <vel_geo>58.505</vel_geo>
     <vel_helio>40.573</vel_helio>
     <rad_obs_ra>45.1926</rad_obs_ra>
     <rad_obs_dec>57.7185</rad_obs_dec>
     <rad_geo_ra>45.8621</rad_geo_ra>
     <rad_geo_dec>57.6263</rad_geo_dec>

     <!-- Uncertainties -->
     <e_q>0.0041</e_q>
     <e_a>1.61</e_a>
     <e_e>0.021</e_e>
     <e_i>0.21</e_i>
     <e_omega>1.02</e_omega>
     <e_asc_node>0.00000049</e_asc_node>
     <e_t0>59.2</e_t0>
     <e_m0>0.24</e_m0>
     <e_mag_abs>0.73</e_mag_abs>
     <e_mass>0.11</e_mass>
     <e_vel_geo>0.22</e_vel_geo>
     <e_vel_helio>0.23</e_vel_helio>
     <e_rad_obs_ra>0.44</e_rad_obs_ra>
     <e_rad_obs_dec>0.10</e_rad_obs_dec>
     <cov_rad_obs>0.00023</cov_rad_obs>
     <e_rad_geo_ra>0.75</e_rad_geo_ra>
     <e_rad_geo_dec>0.50</e_rad_geo_dec>
     <cov_rad_geo>0.00041</cov_rad_geo>
     <e_state>
       0.10,12474.3,14964.5,13142.7,3.12,6.34,7.44,
       0.145,0.574,0.134,0.136,0.245,0.244
     </e_state>

     <!-- Reference to single-station data -->
     <meteors>2</meteors>
     <meteor_code>CAM-20070812-ICC2-M061</meteor_code>
     <meteor_code>CAM-20070812-LCC3-M008</meteor_code>

     <!-- Trajectory information -->
     <traject_pos>
       <pos_no>1</pos_no>
       <time>2007-08-13T00:16:05.68123</time>
       <lon>13.822943</lon>
       <lat>47.084535</lat>
       <height>115.372</height>
       <mag_abs>3.182</mag_abs>
       <e_time>0.00071</e_time>
       <e_lon>0.00062</e_lon>
       <e_lat>0.00042</e_lat>
       <e_height>0.12</e_height>
       <e_mag_abs>0.76</e_mag_abs>
     </traject_pos>
     <traject_pos>
       <pos_no>2</pos_no>
       <time>2007-08-13T00:16:05.69872</time>
       <lon>13.816761</lon>
       <lat>47.080943</lat>
       <height>114.636</height>
       <mag_abs>2.871</mag_abs>
       <e_time>0.00071</e_time>
       <e_lon>0.00037</e_lon>
       <e_lat>0.00043</e_lat>
       <e_height>0.10</e_height>
       <e_mag_abs>0.68</e_mag_abs>
     </traject_pos>

     ...

   </orbit>

 </orbit_set>

</vmo>
```


Figure 3 – Example of a meteoroid orbit in the VMO format. Note that the right column of this figure needs to be stored below the left column in a real file. The line-breaks and whitespaces inside <state> and <e_state> are not allowed, but have been added for readability.

Table 1 – <**vmo**> element: the root element which must appear exactly once in each VMO file and encloses all the data.

Name	#	Description	Example(s)	Type
observer	0..N	A person observing or researching meteors, see Table 2.		<observer>
location	0..N	An observing site, see Table 3.		<location>
cam_system	0..N	Video or photographic equipment, see Table 4.		<cam_system>
cam_session	0..N	Video or photographic observing session, see Table 5.		<cam_session>
orbit_pipeline	0..N	Orbit determination procedure details, see Table 9.		<orbit_pipeline>
orbit_set	0..N	A set of computed meteoroid orbits and trajectories, see Table 10. These sets are similarly motivated like the camera sessions as to group data into packages for more convenient handling.		<orbit_set>
visual	0..N	Visual observing session. To be defined in the follow-up WGN paper.		<visual>
fireball	0..N	Fireball report. To be defined in the follow-up WGN paper.		<fireball>

Table 2 – <**observer**> element: contact information for a person, such as a visual observer or the operator of a video station. Each observer is uniquely identified by the *observer_code*, which is used by other elements to refer to an observer.

Name	#	Description	Example(s)	Type
observer_code	1	Unique alphanumeric identification code for the person, in uppercase. This code has to be unique within each file, and should preferably be registered centrally at http://vmo.imo.net to avoid conflicts.	'ARLRA'	string
first_name	1	Given names and optionally also the middle name. All characters from the extended latin alphabet may be used. For other alphabets, use the English transcription. Avoid nicknames.	'Rainer'	string
last_name	1	Last name(s). Again, only characters from the extended latin alphabet should be used.	'Arlt'	string
address1	0..1	Address line 1.		string
address2	0..1	Address line 2.		string
address3	0..1	Address line 3.		string
postal_code	0..1	Postal code.		string
city	0..1	City of residence.	'Berlin'	string
country_code	1	Two-letter ISO 3166 country code of residence.	'DE'	string
birth_year	0..1	Year of birth. Note that this field is optional.	'1991'	integer
email	0..1	E-mail address.	'visual@imo.net'	string
url	0..1	Personal or institute web site.	'www.rainerarlt.de'	string
affiliation	0..1	Institute, club or association. Enter more than one if needed.	'AKM'	string
comments	0..1	A comment field allowing free text.		string
file	0..N	Attach one or more files, for example a photo of the observer. See Table 13.		<file>

Table 3 – <**location**> element: information on an observing site. Each location is uniquely identified by the *location_code*, which is used by other elements to refer to a location.

Name	#	Description	Example(s)	Unit	Type
location_code	1	Unique alphanumeric identification code for the location, in uppercase. This code has to be unique within each file, and should preferably be registered centrally at http://vmo.imo.net to avoid conflicts.	'DEPOTS'		string
name	1	Administrative name of the town or village, optionally followed by a more specific name of the site.	'Potsdam, Astrophysical Institute'		string
country_code	1	Two-letter ISO 3166 country code.	'DE'		string
lon	1	Geographic longitude in decimal degrees. The longitude should be a signed value between −180 and +180. A negative value means 'WEST', a positive value means 'EAST'. The WGS84 coordinate system should be used, which is also the basis for the GPS system and tools such as Google Earth. Give 5 or more digits behind the decimal sign if meter-accuracy is required.	13.102355	deg	decimal
lat	1	Geographic latitude of the location in decimal degrees. The latitude should be a signed value between −90 and +90. A negative value means 'SOUTH', a positive value means 'NORTH'. The WGS84 coordinate system should be used. Give 5 or more digits behind the decimal sign if meter-accuracy is required.	52.404186	deg	decimal
height	0..1	Height of the location in meters according to the WGS84 coordinate system.	24.3	m	decimal
uncertainty	0..1	Estimated error of the coordinates in meters.	20	m	decimal
comments	0..1	A comment field allowing free text.			string
file	0..N	Attach one or more files, for example a photo of the observing site. See Table 13.			<file>

Table 4 – <**cam_system**> element: information on a video or photographic observing system. Each system is uniquely identified by the *system_code*, which is used by other elements to refer to a system. The actual technical details of the system have to be given in each <cam_session> element, since most components may change frequently and should be specified for each session to ensure correct information.

Name	#	Description	Example(s)	Type
system_code	1	Unique alphanumeric identification code for the system, in uppercase. This code should preferably be registered centrally at http://vmo.imo.net to avoid conflicts.	'ICC3'	string
name	1	Long name of the system.	'ESA/RSSD Intensified CCD Camera #3'	string
system_type	0..1	Type of the system. Should be either 'STILL' (typically one exposure per meteor) or 'VIDEO' (multiple exposures per meteor).	'VIDEO'	string
contact_code	0..1	Contact person for the system, identified by the observer code. The <observer> element for this person should preferably, but not obligatory, be given in the same file.	'KOSDE'	string
comments	0..1	Free text field for comments.	'Built in 1998.'	string
file	0..N	Attach one or more files, for example system documentation. See Table 13.		<file>

Table 5 – **<cam_session>** element: observing session performed using a camera system. A session is an arbitrary collection of observing periods and meteors, typically recorded during a single night. A session also holds the technical details and configuration of the camera system.

Name	#	Description	Example(s)	Type
system_code	1	System identified by the unique code. The corresponding <cam_system> element should preferably, but not obligatory, be given in the same file.	'ICC3'	string
location_code	1	Location of the session, identified by the unique location code. It is compulsory to give the <location> element for this location in the same file.	'NLNOOR'	string
observer_code	1	The contact person for this session, identified by the observer code. It is compulsory to give the <observer> element for this person in the same file.	'KOSDE'	string
version	0..1	Time of last update (used as version identifier).	2009-06-12T18:00:00	datetime
software_code	0..1	Code of the software used to process the data.	'METREC_V3.6'	string
shower_cat_code	0..1	Code of the shower catalog used to identify shower meteors, if shower designations are given in <meteor>.	'IMO2009'	string
camera_code	0..1	Camera body or chip used.	'MINTRON_12v1'	string
prism_code	0..1	Prism or grating used (if any).		string
lens_code	0..1	Lens used.	'FUJINON_12'	string
intensifier_code	0..1	Intensifier used (if any).	'DEP_42'	string
relay_lens_code	0..1	Lens that filmed the output of the intensifier (if any).	'RELAY_1'	string
digitizer_code	0..1	Device used to digitize the exposures.	'MATROX_METEOR2'	string
gain	0..1	Free description of the gain setting.	'Highest gain'	string
storage	0..1	Description of any intermediate storage (e.g., VCR tape, analog film, MPEG-compressed digital file).	'KODAK_400_ASA'	string
interlaced_flag	0..1	Does the camera use the interlaced video format? Leavy empty for a still camera.	true, false	boolean
interlaced_order	0..1	Order of the interlaced fields: 'ODD' or 'EVEN'.	'ODD', 'EVEN'	string
exposure_time	0..1	Length of each exposure in decimal seconds. If interlaced fields are used, give the exposure time for each field. If the exposure time varied, leave empty.	0.02, 0.1, 36000.0	decimal
sampling_interval	0..1	Interval between the beginnings of exposures in decimal seconds. If interlaced fields are used, give the interval between 2 fields.	0.02	decimal
shutter_flag	0..1	Did the system have a rotating shutter to make breaks in the meteor trail?	true, false	boolean
shutter_frequency	0..1	Frequency of the shutter, use breaks per second.	8.64	decimal
shutter_description	0..1	Precise description of the shutter shape. Attach a drawing if necessary.	'The equal-sized blades interrupt the light 8.64 times per second.'	string
fov_vertical	0..1	Vertical size of the field of view in degrees.	40	decimal
image_scale	0..1	Approximate image scale in degrees per pixel.	0.001	decimal
effective_x	0..1	Effective number of pixels in the x (horizontal) direction, taking into account all components of the system. If interlaced fields are used, give the resolution of a single field.	320	integer
effective_y	0..1	Effective number of pixels in the y (vertical) direction, taking into account all components of the system. If interlaced fields are used, give the resolution of a single field.	240	integer
depth	0..1	The number of brightness steps the system can distinguish, taking into account all components.	256	integer
saturation_value	0..1	Saturation value of the pixels.	255	string
color_flag	0..1	Does the system record color?	true, false	boolean
e_time	0..1	Uncertainty (σ) of the clock, use decimal seconds.	2.05	decimal
e_astrometry	0..1	Uncertainty (σ) of the astrometric model, use decimal degrees.	0.051	decimal
comments	0..1	Free text field for comments.		string
period	1..N	One or more observing periods, as specified in Table 6.		<period>
file	0..N	Attach one or more files, for example the session log file. See Table 13.		<file>

Table 6 – <**period**> element: describes the observing conditions and observed meteors in a given interval.

Name	#	Description	Example(s)	Unit	Type
start	0..1	Time when the observation started. Leave empty if unknown (do not just enter the time of the first meteor). Use the ISO 8601 format in Universal Time (UTC).	2007-08-11T23:46:27		datetime
stop	0..1	Time when the observation ended. Leave empty if unknown (do not just enter the time of the last meteor). Use the ISO 8601 format in Universal Time (UTC).	2007-08-12T00:47:54		datetime
teff	0..1	Effective observing time for activity analysis. Leave empty if unknown.	0.975	h	decimal
lm	0..1	Average limiting stellar magnitude during the period.	6.52	mag	decimal
fov_alt	0..1	Measured altitude of the center of the field of view above the horizon in the middle of the period.	32.66	deg	decimal
fov_az	0..1	Measured azimuth of the center of the field of view in the middle of the period. North is 0, east is 90, and so forth.	241.34	deg	decimal
fov_rotation	0..1	Rotation of the field of view in counter-clockwise direction in the middle of the period. Measured as the angle between y-axis and the direction to zenith.	5	deg	decimal
fov_guided_flag	0..1	Is the camera guided, i.e. do the equatorial coordinates of the field of view remain constant throughout the period?	true, false		boolean
fov_obstruction	0..1	Average percentage of the field of view that is obstructed by clouds, trees, buildings, etc. during the period. This should be a number between 0 and 100.	20.5	%	decimal
e_teff	0..1	Uncertainty (σ) of teff.	0.050	h	decimal
e_lm	0..1	Uncertainty (σ) of lm.	0.25	mag	decimal
e_fov_obstruction	0..1	Uncertainty (σ) of fov_obstruction.	5.0	%	decimal
meteor	0..N	Observed meteors, as specified in Table 7.			<meteor>
file	0..N	Attach one or more files, for example the period log file. See Table 13.			<file>

Table 7 – <**meteor**> element: describes a meteor observed by a camera.

Name	#	Description	Example(s)	Unit	Type
meteor_code	0..1	Unique alphanumeric identification code for the meteor. Use the format 'CAM-YYYYMMDD-SYSTEM-M999' (all uppercase), where YYYYMMDD refers to the date on which the session started, SYSTEM refers to the unique code of the camera system, and 999 refers to the relative number of the meteor in the session. For example, the first meteor observed by system ICC3 in the session that started on 2007 August 11 should be called 'CAM-20070811-ICC3-M001'. In case a multiple sessions have started on the same date, append '-N' after the date, where N is the number of the session. For example, the first meteor of the second session is 'CAM-20070811-2-ICC3-M001'. In case more than 999 meteors are seen in a session, add extra digits to the meteor number, e.g., 'CAM-20070811-ICC3-M1000'.	'CAM-20070811-ICC3-M001'		string
time	0..1	Time when the meteor was first detected. Use the ISO 8601 format in Universal Time (UTC).	2007-08-12T00:12:34.45		datetime
shower_code	0..1	The shower designation for the meteor. Initially this is the shower or sporadic source as designated by the observing software, but this value may be recomputed and updated at any point in time afterwards according to an updated standard radiant catalog. 'SPO' is also valid.	'PER'		string
exposures	0..1	Number of exposures in which the meteor was recorded (1 if the observation was photographic).	8		integer
duration	0..1	Duration of the meteor.	1.64	s	decimal
mag	0..1	Brightest instrumental magnitude. The magnitude is "instrumental" because it depends on the spectral response curve of the camera, which may differ from a visual observer.	3.52	mag	decimal
speed	0..1	Average angular speed.	20.30	deg/s	decimal
in_fov	0..1	Denotes whether the meteor entered or left the field of view. '00' = started and ended outside the field of view, '10' = started inside but ended outside, '01' = started outside but ended inside, '11' = both start and end are inside the field of view.	'11'		string
begin_ra	0..1	Right Ascension (J2000.0) of the begin point. The value may have been corrected, e.g. using a linear fit through the meteor or by manual measurement.	20.8753	deg	decimal
begin_dec	0..1	Declination (J2000.0) of the above.	45.4875	deg	decimal
end_ra	0..1	Right Ascension (J2000.0) of the end point. The value may have been corrected, e.g. using a linear fit through the meteor or by manual measurement.	12.8754	deg	decimal
end_dec	0..1	Declination (J2000.0) of the above.	49.7851	deg	decimal
comments	0..1	Free text field for comments.			string
e_duration	0..1	Uncertainty (σ) of duration.	0.13	s	decimal
e_mag	0..1	Uncertainty (σ) of mag.	0.21	mag	decimal
e_speed	0..1	Uncertainty (σ) of speed.	0.54	deg/s	decimal
e_begin_ra	0..1	Uncertainty (σ) of begin_ra.	0.0031	deg	decimal
e_begin_dec	0..1	Uncertainty (σ) of begin_dec.	0.0025	deg	decimal
cov_begin	0..1	Covariance of begin_ra and begin_dec.	0.000035	deg^2	decimal
e_end_ra	0..1	Uncertainty (σ) of end_ra.	0.0022	deg	decimal
e_end_dec	0..1	Uncertainty (σ) of end_dec.	0.0015	deg	decimal
cov_end	0..1	Covariance of end_ra and end_dec.	0.000081	deg^2	decimal
pos	0..N	Optional instanteneous astrometric or photometric measurements, as specified in Table 8.			<pos>
file	0..N	Attach one or more files, for example the meteor sum image. See Table 13.			<file>

Table 8 – <**pos**> element: describes the astrometric and photometric measurements of a meteor frame.

Name	**#**	**Description**	**Example(s)**	**Unit**	**Type**
pos_no	1	Number of the position, counted relative to each meteor starting at 1.	1, 2, 3, 4, 5, ...		integer
time	0..1	Time of the position, accurate to the time interval between exposures or shutter breaks. Use the ISO 8601 format in Universal Time (UTC).	2007-08-12T00:12:34.45		datetime
mag	0..1	The instrumental brightness of the meteor at the given position.	3.64	mag	decimal
pos_x	0..1	The horizontal position (x) of the meteor within the exposure. This should be a relative value between 0 and 1. The left edge is 0, the right edge is 1.	0.231		decimal
pos_y	0..1	The vertical position (y) of the meteor within the exposure. This should be a relative value between 0 and 1. The bottom edge is 0, the top edge is 1.	0.454		decimal
pos_ra	0..1	Right Ascension (J2000.0) of the meteor position.	32.9785	deg	decimal
pos_dec	0..1	Declination (J2000.0) of the meteor position.	130.4845	deg	decimal
correction_flag	0..1	Was the position corrected afterwards, for example by a manual re-measurement?	true, false		boolean
outlier_flag	0..1	Are the given coordinates outliers relative to the other positions for this meteor?	true, false		boolean
saturation_flag	0..1	Was the camera saturated? This means the measurement is less accurate.	true, false		boolean
e_time	0..1	Uncertainty (σ) of time.	0.062	s	decimal
e_mag	0..1	Uncertainty (σ) of mag.	0.23	mag	decimal
e_pos_x	0..1	Uncertainty (σ) of pos_x.	0.017		decimal
e_pos_y	0..1	Uncertainty (σ) of pos_y.	0.018		decimal
e_pos_ra	0..1	Uncertainty (σ) of pos_ra.	0.0035	deg	decimal
e_pos_dec	0..1	Uncertainty (σ) of pos_dec.	0.0028	deg	decimal
cov_ra_dec	0..1	Covariance of pos_ra and pos_dec.	0.000042	deg^2	decimal
file	0..N	Attach one or more files, for example the frame image. See Table 13.			<file>

Table 9 – <**orbit_pipeline**> element: describes a pipeline of software and methods used to determine orbits. This is important as meteor scientists prefer to know the exact methods and tools used in the computation of an orbit. Note that the examples shown in this table are kept very short for formatting reasons; in reality one should attempt to give much more details.

Name	#	Description	Example(s)	Type
pipeline_code	1	Unique code of the orbit determination pipeline.	'UFO2.21'	string
contact_code	1	The contact person, identified by the observer code refering to the <observer>...</observer> element.	'SONOTACO'	string
name	1	Long name of the pipeline (typically the full name of a software package, including the version number and author name).	'UFOOrbit 2.21 by SonotaCo'	string
description	1	General description of the methods and software used to determine the orbit.	'Uses the UFO tools available from http://www.sonotaco.com.'	string
astrometry	0..1	Describe how astrometry was obtained from raw images. If astrometry from an existing database was used, note it here. Provide references if possible. Leave empty for radar orbits.	'Uses UFOAnalyzer 2.25 by SonotaCo. Described in detail in Sonotaco et al (2008), WGN.'	string
trajectory	1	Describe the trajectory determination algorithm. Provide references if possible.	'Ceplecha (1987).'	string
errors	1	Describe how the uncertainties in the astrometry, trajectory and orbit are estimated.	'Uncertainties were propagated from the astrometry to the orbit using Monte-Carlo (1000 iterations).'	string
mass	0..1	Describe how the mass was computed, and specify if the mass is photometric or dynamical. Provide references if possible.	'Photometric mass. ReVelle & Ceplecha (2002), ESA SP-500'	string
comments	0..1	Free text field to provide additional documentation and comments.	'If this was a real example, there should be much more text!'	string
file	0..N	Attach one or more files, for example pipeline documentation or reference papers. See Table 13.		<file>

Table 10 – <**orbit_set**> element: groups a set of orbits/trajectories.

Name	#	Description	Example(s)	Type
set_code	1	Code for this collection of orbits. Use '`ORB-OBSERVERCODE-NAME`' in uppercase characters, where `OBSERVERCODE` is the unique observer code of the author/contact person, and `NAME` is an arbitrary name of the set (using alphanumeric characters without spaces). For example, Perseid 2009 orbits computed by Rainer Arlt could be called '`ORB-ARLRA-PER2009`'.	'ORB-ARLRA-PER2009'	string
contact_code	1	The author or contact for this set of orbits, identified by the unique observer code refering to the <observer>...</observer> element.	'ARLRA'	string
version	0..1	Time of last update (used as version identifier).	2009-06-12T18:00:00	datetime
comments	0..1	Free text field to provide comments.		string
orbit	1..N	One or more heliocentric meteoroid orbits. See Table 11.		<orbit>
file	0..N	Attach one or more files, for example a documentation for this specific set of orbits. See Table 13.		<file>

Table 11 – <**orbit**> element: a meteoroid trajectory/orbit computed from two or more camera stations (or one radar station). The orbital elements must be given in the heliocentric reference frame J2000.

Name	**#**	**Description**	**Example(s)**	**Unit**	**Type**
pipeline_code	0..1	Code of the orbit computation pipeline used. A corresponding <orbit_pipeline> element should be present in the file, describing in detail how the orbit was computed.	'UFO2.21'		string
orbit_type	1	Type of observations used to determine the orbit. Should be either 'VISUAL', 'STILL', 'VIDEO', 'RADAR' or 'HYBRID'. If 'STILL' and 'VIDEO' data is combined, use 'VIDEO'. For any other combination, use 'HYBRID' and explain in comments.	'VIDEO'		string
time	1	Reference time for the meteor; when the meteoroid was at 100 km height. Use the ISO 8601 format in UTC.	1993-04-21T23:20:24		datetime
t0	0..1	Epoch (seconds since J2000.0) for which the orbital elements are given. The epoch is not necessarily the same as the meteor reference time, because the orbital elements may be given for an earlier point in time.	−211248000.3	s	decimal
q	0..1	Perihelion distance (small q).	0.9381	AU	decimal
a	0..1	Semimajor axis.	6.36	AU	decimal
e	0..1	Eccentricity.	0.8537		decimal
i	0..1	Inclination.	80.3717	deg	decimal
omega	0..1	Argument of periapsis.	211.3147	deg	decimal
asc_node	0..1	Ascending node (J2000.0).	31.9439467	deg	decimal
m0	0..1	Mean anomaly at epoch t0.	69.4212	deg	decimal
shower_code	0..1	Code of the meteoroid stream that fits the orbital elements (if any).	'LYR'		string
iau_no	0..1	IAU number of the meteoroid stream that fits the orbital elements (if any).	'0006'		string
mag_abs	0..1	Absolute maximum brightness in the visual spectral range expressed as a magnitude. This is the brightness that would be recorded if the meteor was at a height of 100 km in the zenith of a visual observer.	−3.27	mag	decimal
mass	0..1	Meteoroid mass in grams.	1734	g	decimal
vel_obs	0..1	Observed velocity *without any correction* for atmospheric deceleration, diurnal abberation or zenith attraction.	47.60	km/s	decimal
vel_inf	0..1	Velocity just before atmospheric entry (= vel_obs corrected for atmospheric deceleration and diurnal aberration).	47.70	km/s	decimal
vel_geo	0..1	Geocentric velocity (= vel_inf corrected for zenith attraction).	46.15	km/s	decimal
vel_helio	0..1	Heliocentric velocity (= vel_geo converted to the heliocentric reference frame).	40.32	km/s	decimal
height_begin	0..1	Height at meteor begin point (leave empty if the begin point was not observed).	103.44	km	decimal
height_max	0..1	Height at the point of brightest absolute magnitude.	79.23	km	decimal
height_end	0..1	Height at meteor end point (leave empty if the end point was not observed).	77.02	km	decimal
rad_obs_ra	0..1	Right Ascension (J2000.0) of the observed radiant. This is the radiant *without any correction* for atmospheric deceleration, diurnal abberation or zenith attraction.	274.1984	deg	decimal
rad_obs_dec	0..1	Declination (J2000.0) of the above.	33.5586	deg	decimal
rad_geo_ra	0..1	Right Ascension (J2000.0) of the geocentric radiant. This is the radiant corrected for atmospheric deceleration, diurnal aberation and zenith attraction.	274.7741	deg	decimal
rad_geo_dec	0..1	Declination (J2000.0) of the above.	33.2541	deg	decimal
z_avg	0..1	Average zenith distance of the observed radiant from the different stations.	51.41	deg	decimal
meteors	0..1	Total number of single-station meteor observations used to compute the orbit.	2,3...		integer
meteor_code	0..N	Codes of the meteors used to determine the orbit. The corresponding <meteor> elements (cf. Table 7) should preferably be given in the same file or be available in a central archive.			string
complete	0..1	Could the meteor trajectory be reconstructed completely from the available data? '11' = yes; '01' = begin is missing; '10' = end is missing; '00' = begin and end are missing.	'11'		string

Table 11 – <**orbit**> element (continued).

Name	#	Description	Example	Unit	Type
conv_best	0..1	Best (closest to 90°) convergence angle. This is the angle between the apparent great circles of meteor motion as seen from any two observing stations; indicating the quality of the observing geometry. Leave empty for radar orbits.	64.5	deg	decimal
state	0..1	7-element state vector $(t, x, y, z, v_x, v_y, v_z)$ of the meteoroid while producing the meteor; t is the ISO 8601 timestamp in UTC, x, y, z are the rectangular Geocentric coordinates in the Earth-fixed reference frame (the X-axis points towards 0 degrees longitude/latitude, the Z-axis points North along the axis of rotation of the Earth, and the Y-axis is the cross product of X and Z), and v_x, v_y, v_z are the velocities in the same reference frame. The state vector should be corrected for atmospheric deceleration and diurnal aberration, but not for zenith attraction. This vector allows for the easy recomputation of orbital elements using different algorithms and reference epochs. It is strongly advised to provide this field.	1993-04-21 T23:20:24, 5268456.3, 2799969.6, 2516762.2, 31826.2, −24824.2, 41340.3	time, m, m, m, m/s, m/s, m/s	vector
e_state	0..1	Uncertainty variances and covariances of the state vector. Use the following format: $(\sigma_t^2, \sigma_x^2, \sigma_y^2, \sigma_z^2, \sigma_{v_x}^2, \sigma_{v_y}^2, \sigma_{v_z}^2, \mathrm{cov}(x, y)$, $\mathrm{cov}(x, z)$, $\mathrm{cov}(y, z)$, $\mathrm{cov}(v_x, v_y)$, $\mathrm{cov}(v_x, v_z)$, $\mathrm{cov}(v_y, v_z))$	0.001, 1328.3, 1447.5, 1396.7, 12.5, 69.1, 32.4, 0.145, 0.574, 0.134, 0.136, 0.245, 0.244	s^2, m^2, m^2, m^2, m^2/s^2, m^2/s^2, m^2/s^2, m^2, m^2, m^2, m^2/s^2, m^2/s^2, m^2/s^2	vector
e_time	0..1	Uncertainty (σ) of time.	1.3	s	decimal
e_t0	0..1	Uncertainty (σ) of t0.	1.3	s	decimal
e_q	0..1	Uncertainty (σ) of q.	0.0052	AU	decimal
e_a_inv	0..1	Uncertainty (σ) of 1/a. The error of the *inverse* of the semi-major axis is asked because this quantity follows a normal distribution. The error distribution of the semi-major axis itself is heavily skewed.	1.89	AU	decimal
e_e	0..1	Uncertainty (σ) of e.	0.040	AU	decimal
e_i	0..1	Uncertainty (σ) of i.	0.64	deg	decimal
e_omega	0..1	Uncertainty (σ) of omega.	1.42	deg	decimal
e_asc_node	0..1	Uncertainty (σ) of asc_node.	0.000012	deg	decimal
e_m0	0..1	Uncertainty (σ) of m0.	0.023	deg	decimal
e_mag_abs	0..1	Uncertainty (σ) of mag_abs.	0.54	mag	decimal
e_mass	0..1	Uncertainty (σ) of mass.	102	g	decimal
e_vel_obs	0..1	Uncertainty (σ) of vel_obs.	0.58	km/s	decimal
e_vel_inf	0..1	Uncertainty (σ) of vel_inf.	0.58	km/s	decimal
e_vel_geo	0..1	Uncertainty (σ) of vel_geo.	0.47	km/s	decimal
e_vel_helio	0..1	Uncertainty (σ) of vel_helio.	0.42	km/s	decimal
e_height_begin	0..1	Uncertainty (σ) of height_begin.	2.33	km	decimal
e_height_max	0..1	Uncertainty (σ) of height_max.	1.87	km	decimal
e_height_end	0..1	Uncertainty (σ) of height_end.	1.56	km	decimal
e_rad_obs_ra	0..1	Uncertainty (σ) of rad_obs_ra.	0.075	deg	decimal
e_rad_obs_dec	0..1	Uncertainty (σ) of rad_obs_dec.	0.050	deg	decimal
cov_rad_obs	0..1	Covariance of rad_obs_ra and rad_obs_dec.	0.00023	deg^2	decimal
e_rad_geo_ra	0..1	Uncertainty (σ) of rad_geo_ra.	0.075	deg	decimal
e_rad_geo_dec	0..1	Uncertainty (σ) of rad_geo_dec.	0.050	deg	decimal
cov_rad_geo	0..1	Covariance of rad_geo_ra and rad_geo_dec.	0.00041	deg^2	decimal
comments	0..1	Free text field for comments.			string
traject_pos	0..N	Optional instantaneous position along the trajectory of the meteoroid as specified in Table 12			<traject_pos>
file	0..N	Attach one or more files, for example an orbit graph. See Table 13.			<file>

Table 12 – <**traject_pos**> element: describes a point on the trajectory of the meteor. This element may be used multiple times inside <orbit> to describe the atmospheric trajectory of a meteoroid in geographic coordinates.

Name	#	Description	Example(s)	Unit	Type
pos_no	1	Number of the point, counted relative to each trajectory starting at 1.	1, 2, 3, 4, 5...		integer
time	0..1	Time when the meteoroid was at the given position. Use the ISO 8601 format in Universal Time (UTC).	2007-08-12T00:12:35.24		datetime
lon	0..1	Geographic longitude in decimal degrees. The longitude should be a signed value between −180 and +180. A negative value means 'WEST', a positive value means 'EAST'. The WGS84 coordinate system should be used, which is also the basis for the GPS system.	13.148752	deg	decimal
lat	0..1	Geographic latitude in decimal degrees. The latitude should be a signed value between −90 and +90. A negative value means 'SOUTH', a positive value means 'NORTH'. The WGS84 coordinate system should be used.	52.516435	deg	decimal
height	0..1	Geographic height above zero in kilometer, relative to WGS84.	87.1549	km	decimal
mag_abs	0..1	Absolute brightness in the visual spectral range expressed as a magnitude. This is the brightness that would be recorded if the meteor was in a visual observer's zenith at a height of 100 km.	−2.4	mag	decimal
vel	0..1	Velocity between this and the following <traject_pos>.	46.53	km/s	decimal
e_time	0..1	Uncertainty (σ) of time.	0.14	s	decimal
e_lon	0..1	Uncertainty (σ) of lon.	0.00045	deg	decimal
e_lat	0..1	Uncertainty (σ) of lat.	0.00071	deg	decimal
e_height	0..1	Uncertainty (σ) of height.	0.0041	km	decimal
cov_lon_lat	0..1	Covariance of lon and lat.	0.00056	deg^2	decimal
cov_lon_height	0..1	Covariance of lon and height.	0.00024	deg·km	decimal
cov_lat_height	0..1	Covariance of lat and height.	0.00083	deg·km	decimal
e_mag_abs	0..1	Uncertainty (σ) of mag_abs.	0.42	mag	decimal
e_vel	0..1	Uncertainty (σ) of vel.	1.3	km/s	decimal

Table 13 – <**file**> element: allows files in custom formats to be attached.

Name	#	Description	Example(s)	Type
path	1	Location of the file relative to the location of the XML document. Can also be a remote URL.	'videos/vid287.avi'	string
comments	0..1	A comment field allowing free text.		string