Using incompatible fireball camera systems to find meteorites – towards a data exchange standard

Jim Rowe[1], L. Daly[2,3,4,5], S. McMullan[5,7], H.A.R. Devillepoix[3], G.S. Collins[5,7], François Colas[1,6], M. Suttle[5,8], Q.H.S. Chan[5,9], J.S. Young[5,10], C. Shaw[5,11], A.G. Mardon[5,12], M. Alexander[5,13], Jonathan Tate[5,14], The Desert Fireball Network Team[3], The FRIPON Core Team[6], Peter Campbell-Burns[1,15], Richard Kacerek[1,15], Davy Jones[15], Richard Fleet[15], Ashley King[1,16], Katherine Joy[1,17], Apostolos Christou[1,12,18], Jana Horák[1,19], Denis Vida[20], Jamie Shepherd, Jonathan Mackey[21,22], Samuel Green[21,22], Nicholas Pochinkov[21,23], Mike Hankey[24,25]

[1]SCAMP fireball network, UK.
[2]School of Geographical and Earth Sciences, University of Glasgow, Glasgow, G12 8QQ, UK
[3]Space Science and Technology Centre, School of Earth and Planetary Sciences, Curtin University, GPO Box U1987, Perth, WA, 6845, Australia.
[4]Australian Centre for Microscopy and Microanalysis, The University of Sydney, NSW, 2006, Australia.
[5]UK Fireball Network.
[6]FRIPON, IMCCE, Observatoire de Paris, PSL Research University, CNRS UMR 8028, Sorbonne Université, Université de Lille, 77 av. Denfert-Rochereau, 75014, Paris, France.
[7]Impact and Astromaterials Research Centre, Department of Earth Science and Engineering, Imperial College London, SW7 2AZ, UK.
[8]Natural History Museum, London, SW7 5BD, UK.
[9]Department of Earth Sciences, Royal Holloway University, Egham Hill, Egham TW20 0EX, UK.
[10]University of Cambridge, Mullard Radio Astronomy Observatory, Cambridge Road, Harlton, Cambridgeshire, CB23 1EX, UK.
[11]Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK.
[12]Newby Hall and Gardens, Ripon, Yorkshire, HG4 5AE, UK.
[13]Galloway Astronomy Centre, Glasserton, Nr Whithorn, DG8 8NE, UK.
[14]The Spaceguard Centre, Llanshay Lane, Knighton, LD7 1LW, UK.
[15]UK Meteor Observation Network, UK.
[16]School of Physical Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK.
[17]School of Earth & Environmental Sciences, The University of Manchester, Oxford Rd, Manchester M13 9PL, UK.
[18]Armagh Observatory and Planetarium, College Hill, Armagh BT61 9DB, UK.
[19]Mineralogy & Petrology, Department of Natural Sciences, Amgueddfa Cymru – National Museum Wales, Cathays Park, Cardiff, CF10 3NP.
[20]Department of Earth Sciences, University of Western Ontario, London, Ontario, N6A 5B7, Canada.
[21]Dublin Institute for Advanced Studies, Astronomy & Astrophysics Section, 31 Fitzwilliam Place, Dublin 2, Ireland
[22]Centre for AstroParticle Physics and Astrophysics (CAPPA), DIAS Dunsink Observatory, Castleknock, D15 XR2R, Ireland
[23]School of Physics, Trinity College Dublin, the University of Dublin, College Green, Dublin 2, Ireland.
[24]American Meteor Society Ltd.
[25]International Meteor Organization, Belgium.

(jim.rowe@scamp.org.uk)

Draft 2.06, 6th August 2020

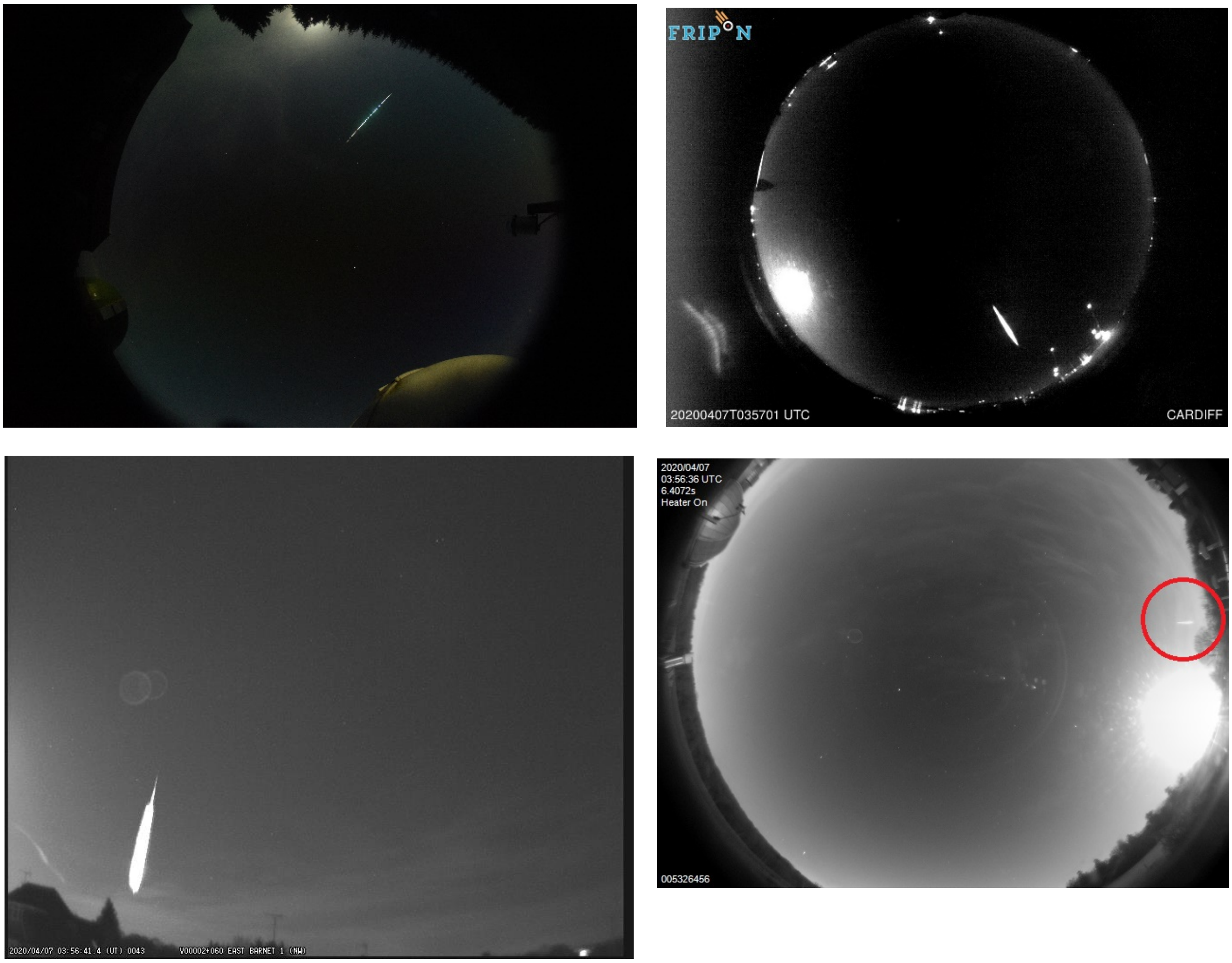

Figure 1: The same fireball seen by four different camera systems in the UK:

- Top left: UK Fireball Network (Desert Fireball Network),
- Top right: SCAMP/FRIPON,
- Bottom left: UK Meteor Observation Network's UFOCapture system, and
- Bottom right: the Bayfordbury all-sky camera run by the Department of Physics, Astronomy and Mathematics, University of Hertfordshire.

Getting these camera systems to talk to each other is a necessary part of using them to find meteorites falling in the UK. This fireball was over mid Wales at 03:56 UTC on 2020 April 7th, and is unlikely to have dropped a meteorite.

Contents

Summary

When looking for recently-fallen meteorites, using all observations of a fireball event from each network is necessary to calculate a precise orbit and fall position. However, in the UK there are five meteor camera networks using four different camera and software systems, and these are not compatible with each other.

The authors have largely solved that problem, and now are working towards agreeing a common format for fireball data exchange. Agreeing a common format enables data sharing but does not require it.

The objectives of this paper are to:

1. Define the minimum and recommended data set for a fireball observation;
2. List several existing possible candidates for such a data exchange format;
3. Evaluate those possible formats and recommend the adoption of one of them;
4. Describe a new code written to translate fireball data outputs from each UK network; and
5. List remaining problems that a common format does not solve, including becoming aware that a fireball event has occurred.

In section 3 below, seven fireball camera systems were examined, from which four candidate data exchange formats were identified and evaluated. Samples of these four formats are appended. As a result of this evaluation, we recommend that a format very similar to that used by the Desert Fireball Network should be adopted as the standard format for exchanging fireball data.

1. The essential and recommended data set

"Essential data" is the minimum fireball data set, without which the observation cannot be used to calculate a trajectory, fall position or orbit.

"Recommended data" identifies the source of the data and includes estimates of the measurement uncertainty and qualitative information. Provision of the "recommended data" should enable the recipient to evaluate the quality and accuracy of the observation.

In the remainder of this paper, data describing the location and observatory are referred to as "metadata" while the set of timed direction vectors is referred to as "point observation data".

1.1 Essential data

For metadata, the minimum requirement is simply the location of the observatory, i.e.:

- Decimal signed latitude (-90 S to +90 N)
- Decimal signed longitude (-180 W to +180 E)
- Altitude in metres (Global Positioning System measurement, i.e. MSL)

Latitude and longitude should be recorded to at least six decimal places, corresponding to about 10cm of positional uncertainty. This is consistent with the stated maximum accuracy of current and proposed GPS devices. Altitude in metres should be the Global Positioning System measurement (MSL) which can differ from the WGS84 altitude.

For point observation data, the minimum requirement for each point observation (e.g. for each half-frame of interlaced video, full frame of non-interlaced video, or shutter cycle for a shuttered non-video camera) is a timed direction vector, i.e.:

- UTC date/time of the point observation
- Right Ascension (RA) – J2000
- Declination (DEC) – J2000

The number of decimal places recorded for RA and Dec should reflect the astrometric precision of the system. Generally, four decimal places are enough for any system currently used to observe fireballs. Whole milliseconds are sufficiently accurate for time measurements.

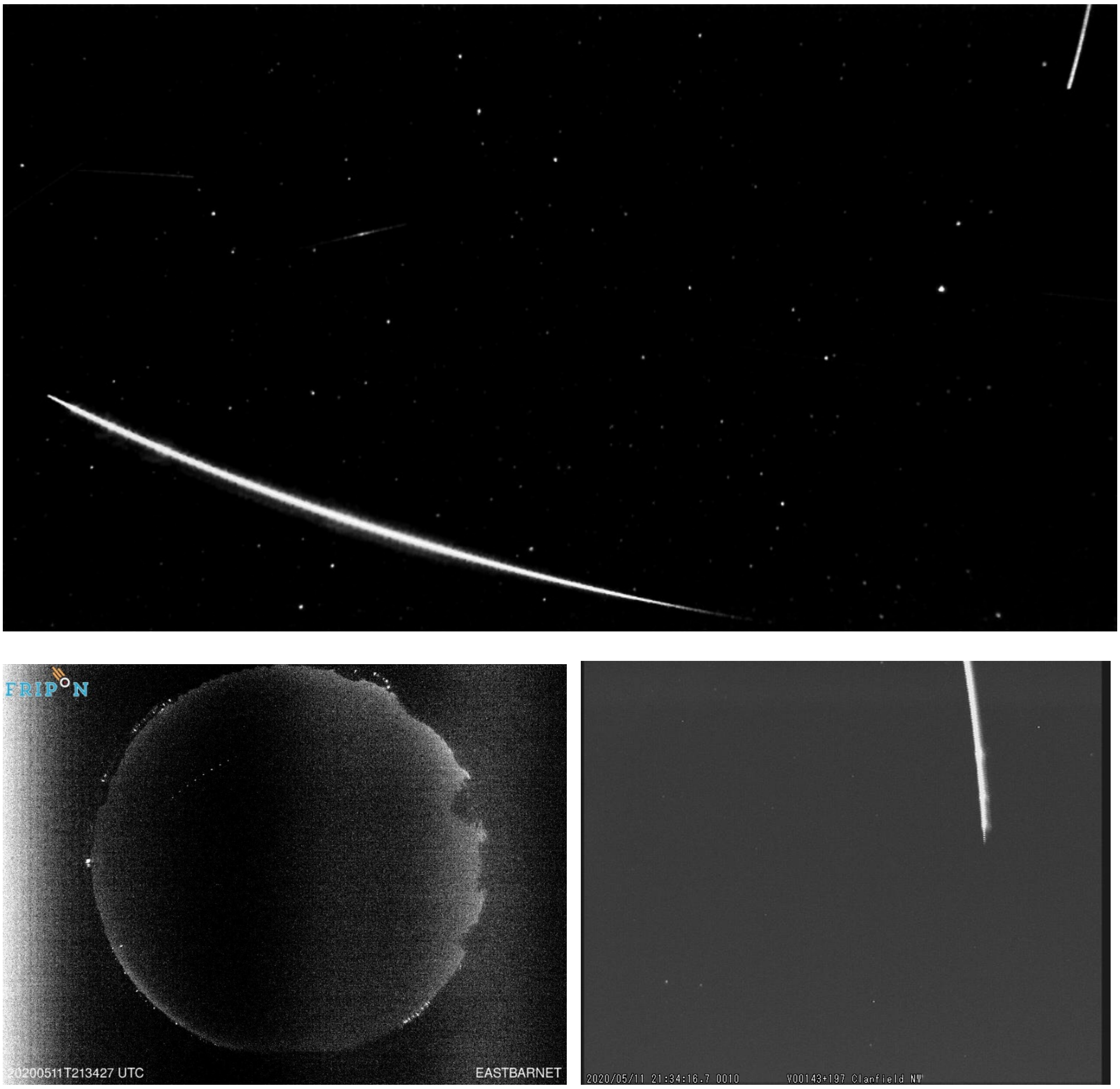

Figure 2: Fireball over Hampshire at 21:34 UTC on 2020 May 11th , seen by four different and incompatible fireball camera systems:

- Top: Global Meteor Network,
- Bottom left: SCAMP/FRIPON,
- Bottom right: Nemetode/UKMON UFOCapture system
- Observed but not shown here: UKFN/DFN

The RA and Dec are derived directly from an astrometric calibration plate which is made by fitting observed stars against a star catalogue. Thus, RA and Dec should always be reported in the data output. The horizontal coordinates, the apparent azimuth and altitude, are derived from RA and Dec, preferably using an atmospheric refraction correction. If certain software does not apply the refraction correction and thus computes the true horizontal coordinates, the difference from apparent coordinates can be on the order of 10s of arc minutes at low altitudes, translating into kilometres of spatial error. Note that during trajectory estimation, true (refraction subtracted, not apparent) coordinates should be used, as the bulk of the refraction-causing atmosphere in most cases will be between the observer and the fireball.

1.2 Recommended data

This additional data identifies the observing station, the camera network and the originating software, and gives some indication of likely temporal accuracy and spatial error terms. While not essential for initial triangulation of the fireball, it does provide a useful indication of data quality and is crucial for future evaluation of the data, reproducibility, and qualitative evaluation, thus it should always be included.

1.2.1 Recommended metadata

A list of recommended metadata is below. These twenty-four items are a pragmatic selection of those most commonly recorded by the seven existing camera systems surveyed. A variety of other measures are recorded by each system or could be recorded[1], but beyond this initial list there is no consensus as to what these should be.

Status	***Explanation***	***Data type***	***Standard***	***Desert Fireball Net***	***UFOAnalyzer***	***FRIPON***	***RMS***	***CAMS***	***AllSkyCams***	***MetRec***
Essential	Observatory latitude	Float	obs_latitude	obs_latitude	lat	Latitude	lat	Latitude +north (de	lat	Latitude
Essential	Observatory longitude	Float	obs_longitude	obs_longitude	lng	Longitude	lon	Longitude +west (d	lng	Longitude
Essential	Observatory MSL	Float	obs_elevation	obs_elevation	alt	Altitude	elev	Height above WGS	alt	Altitude
Recc.	Network name	Text	origin	origin	['UFOAnalyzer']	['FRIPON']	['RMS']	['CAMS']	['All Sky Systems']	['MetRec']
Recc.	Name of location of obs	Text	location	location	lid	City	station_code	Camera number	station	Site code
Recc.	Name of the station	Text	telescope	telescope	lid_sid	Stations	Cam#	Camera number	device	CameraName
Recc.	Coded name of station (	Text	camera_id	dfn_camera_coder	sid (two letters)	Stations	Cam#	Camera number	station	CameraName
Recc.	Person or other name	Text	observer	observer	observer	[calculate]	'RMS'	Camera number	[location+telescop	CameraName
Recc.	Camera make and mode	Text	instrument	instrument	cam	Camera	['Unknown']	Camera descriptio	[unknown]	[unknown]
Recc.	Horizontal pixel count	Int	cx	NAXIS1	cx	[calculate]	X_res	Cal center col (colc	['calib']['img_dim']	TimeStampXPositi
Recc.	Vertical pixel count	Int	cy	NAXIS2	cy	[calculate]	Y_res	Cal center row (rov	['calib']['img_dim']	TimeStampYPositi
Recc.	File as obtained from ca	Text	image_file	image_file	clip_name	['Unknown']	[at top of capture]	file_name	org_hd_vid	inf.path
Recc.	Start datetime of clip	ISO datetime	isodate_start_obs	isodate_start_obs	[calculate]	[calculate]	[calculate]	[calculate]	[calculate]	[calculate]
Recc.	Time of middle of clip	ISO datetime	isodate_mid_obs	isodate_mid_obs	[calculate]	[calculate]	[calculate]	[calculate]	[calculate]	[calculate]
Recc.	Total clip length in seco	Float	exposure_time	exposure_time	[calculate]	[calculate]	[calculate]	[calculate]	[calculate]	[calculate]
Recc.	Number of stars identif	Int	astrometry_numbe	astrometry_numbe	rstar	[0]	len(star_list)	[0]	[calculate]	[0]
Optional	Reference magnitude o	Float	photometric_zero_	photometric_zero_	mimMag	[0.0]	mag_lev	[0]	[0]	[0]
Optional	Uncertainty in mag	Float	photometric_zero_	photometric_zero_	[0.0]	[0.0]	mag_lev_stddev	[0]	[0]	[0]
Optional	Lens make and model	Text	lens	lens	lens	['Unknown']	['Unknown']	Lens description	[unknown]	[unknown]
Optional	Azimuth of camera cent	Float	obs_az	[0.0]	az	[0.0]	az_centre	Cal center Azim (d	['center']['az']	Center of plate Az
Optional	Elevation of camera cen	Float	obs_ev	[0.0]	ev	[0.0]	alt_centre	Cal center Elev (de	['center']['el']	Center of plate Alt
Optional	Rotation of camera	Float	obs_rot	[0.0]	rot	[0.0]	rotation_from_hor	Cam tilt wrt Horiz (	[0]	[0]
Optional	FOV horiz - degrees	Float	fov_horiz	[0.0]	vx	[0.0]	fov_h	FOV width (deg)	[0]	cfg_fov[1]
Optional	FOV vertical - degrees	Float	fov_vert	[0.0]	[0.0]	[0.0]	fov_v	FOV height (deg)	[0]	cfg_fov[2]

Table 1: Recommended metadata, with naming used by seven commonly-deployed meteor or fireball camera systems.

1.2.2 Recommended point observation data

There is currently a wide variation in the point observation data recorded by different systems. A summary of the essential and recommended data that is most common across existing systems is:

[1] See also WGN38:1 (2010), pp 10-24, where a larger data set is specified.

Status	Explanation	Data type	Standard	Desert Fireball Net	UFOAnalyzer	FRIPON	RMS	CAMS	AllSkyCams	MetRec
Essential	Time of point data	ISO datetime	datetime	datetime, datatype: string}		TIME	Decimal frame no.	timestamp	dt	timestamp
Essential	Azimuth, N=0, E=+90	Float	azimuth	azimuth, datatype:	az	[calculate]	Azim	azim	az	[calculate]
Essential	Elevation, zenith = +90	Float	altitude	altitude, datatype:	ev	[calculate]	Elev	elev	el	[calculate]
Essential	Right ascension	Float	ra	[calculate]	ra	ALPHAWIN_J2000	RA	ra	ra	inf['alpha']
Essential	Declination	Float	dec	[calculate]	dec	DELTAWIN_J2000	Dec	dec	dec	inf['delta']
Recc.	Astronomical magnitud	Float	mag	[0.0]	mag	[0.0]	Mag	mag	[0]	inf['bright']
Optional	Location - pixel count	Float	x_image	x_image	[0.0]	XWIN_IMAGE	Col	col	x	inf['x']
Optional	Location - pixel count	Float	y_image	y_image	[0.0]	YWIN_IMAGE	Row	row	y	inf['y']

Table 2: Recommended point observation data, with naming used by seven commonly-deployed meteor or fireball camera systems. RA/Dec are J2000, Alt/Az are true not apparent. RMS is the Raspberry Meteor System which is deployed in the Global Meteor Network ("GMN").

Estimated astronomical magnitude should be included, as the mass of the initial meteoroid can be estimated from the integrated light curve. It can also be used to identify fragmentation events. Images of bright fireballs on meteor camera systems are frequently saturated, so it is often not possible to calculate a trustworthy magnitude estimate from the image. However, aligning the light curves can be useful when quantify timing errors between various observations of the same meteor event, and the apparent magnitude is a standard way of recording the light curve. Overall, a magnitude estimate is useful and should be calculated and recorded for each point observation.

Information regarding positional uncertainty, pixel count and image saturation should also be included. However, at the moment no two systems record this information in the same way. Examples of this sort of data include:

- FRIPON – uses a magnitude estimate designed for galaxy surveys – the "flux within a Kron-like elliptical aperture"[2], along with an estimate of positional error.
- Global Meteor Network – magnitude estimate in the GAIA G band, the sum of pixel intensities for pixels above a given threshold and standard deviation above the mean.
- UFO Analyzer – magnitude estimate and pixel count in the fireball image.
- Desert Fireball Network – a positional uncertainty estimate for each point observation.

In the short term, we propose that each system should record an estimate of astronomical magnitude, as well as their existing data relating to positional uncertainty, pixel count or other measures. In future it could be useful to agree a holistic list of real justifiable measurement uncertainty or magnitude measures which have a clear interpretation independent of the systems producing them. Whilst important, reaching such agreement is outside the scope of this paper.

1.3 Optional data

A wide range of additional data could be included within a fireball observation, including additional metadata and extra columns of point data. Often these items are only meaningful within the originating camera network and become irrelevant when transferred to another camera network. Such data may have unforeseen uses and so its collection may still be valuable. Examples of optional data provided by some fireball camera networks are:

Metadata - optional
- Model of camera
- Model of lens
- Focal length
- Intermediate processing software name, version, operator, filenames, etc.
- Star catalogue used (should not matter which)
- Other astrometry parameters

Point observation data - optional
- Frame number
- Horizontal and vertical pixel position – floating point estimate
- Other descriptors of the point observation

[2] E. BERTIN, SExtractor Draft User's manual v2.13, Institut d'Astrophysique & Observatoire de Paris, 2010.

1.4 What astrometry information should be included?

Accurate astrometry is essential if a fireball observation is to be useful. Each fireball recording system will perform the astrometry in its own unique way.

Of the seven camera systems surveyed, four (GMN, CAMS, MetRec and AllSkyCams) record lens distortion parameters and calibration star lists with each meteor observation. For the other three systems, this information is retrievable from camera configuration or calibration files. However, it is not really clear what value this information has to a recipient. It does not enable the recipient to extract better or more reliable data from the file than if it were omitted.

Data therefore needs to be exchanged with the assumption that the astrometry done by the sending network is adequate. Astrometry information should be recorded and retained for completeness of the dataset and reproducibility, but generally does not need to be exchanged because it is of no use to the recipient.

For a receiving system to check the astrometry, the primary image data needs to be reprocessed using the recipient's image analysis system. This process is often labour-intensive and so represents a second stage of information exchange, beyond the scope of this paper. Data exchanged in the formats reviewed here should be regarded as a good first approximation of the observation, but (for example, as far as the authors can tell) a fragmenting meteoroid can't be recorded in any of these formats, and the camera systems that produce the data in any automated way are also not designed to expect or analyse fragmentation.

Some astrometry information (for example, number of stars used in calibration and the epoch if not J2000) should be flagged or is included in the "recommended" list, above. At this stage however, it is suggested that no astrometry information is classified as "essential" for the purposes of data exchange. In future, rather than focussing on a way to exchange astrometry information, it may be more productive to focus on exchanging primary image data and preparing a "user guide" for each camera system that describes any features of the camera system that affect the interpretation of the primary image data.

1.5 Data that is outside the scope of a fireball observation format

This paper focusses only on single-station fireball observations. In particular, the following topics are outside the scope of the envisaged level of data exchange:

- Trajectories, which are produced by some systems (e.g. DFN and FRIPON) in Google Earth's KML/KMZ format;
- Orbits, which can be exchanged in a variety of ways including the Export Format for Minor-Planet Orbits[3];
- Data exchange for multiple faint meteors or for meteor showers; and
- Data storage, pooling, sharing or consolidation, which whilst important, do not have any bearing on the format of data exchanged.

1.6 Reading and writing the data files

The data file will be written by the camera system and read by a pipeline program designed by each network's operators and also by human operators. Desirable characteristics for a data file format are that it should:

- Be human-readable, so should use ASCII text. No "pickling" or binary.
- Be intelligible, e.g. use ISO date/time and signed decimal degrees.

[3] See https://www.minorplanetcenter.net/iau/info/MPOrbitFormat.html

- Be able to be parsed/read and also written by standard library data dump routines (such as ECSV, XML, JSON or SExtractor) rather than being written item-by-item or line-by-line.
- Not be sensitive to the order of metadata, or to metadata items that it doesn't expect.
- Not be sensitive to column order in the point observation data.
- Avoid deep nesting of data if XML or JSON formats are used, to improve both human and machine readability.
- Clearly state the conventions (e.g. zero azimuth direction), epoch, and units of every measurement.

2. What's out there – existing systems which could be candidates

Seven camera systems currently used in the UK or Europe plus one additional non-hardware-based format have been considered as candidates for adoption as a data exchange standard. These are:

- **UFOAnalyzer.** Used in the UK by the UK Meteor Observation Network and the NEMETODE network, the "A.XML" file produced by UFOAnalyzer contains the essential and recommended data, in an XML format. UFOAnalyzer is widely used by amateurs in the UK, Western Europe, and Japan.

- **Global Meteor Network.** Increasingly deployed in the UK. Observations are recorded in two files, the "platepar" file containing the astrometric and photometric calibration, and the "FTP_detectinfo.txt" file containing individual measurements for all meteors observed in any given night.

- **Desert Fireball Network (DFN)**, UK Fireball Network, Global Fireball Observatory – generates a single file with all essential and recommended data (except RA, Dec and magnitude), written in Astropy ECSV table format.

- **FRIPON, SCAMP -** produces a file in Pixmet or SExtractor format, but lacking metadata, which needs to be added from a separate list of observatory parameters.

- **Cameras for Allsky Meteor Surveillance (CAMS)** – similar to GMN. Used in Benelux countries, which have occasional observational overlap with the UK.

- **All Sky Cams** – Used in the US and Germany and has data files in JSON format that could be suitable as a standard.

- **MetRec** – a system widely used in Germany and Eastern Europe with a long pedigree. As with GMN and CAMS, meteor data and camera data are kept as separate files. These can be read and written with library routines curated by the European Space Agency.

- **Virtual Meteor Observatory[4] (VMO)** – an XML multiple-meteor format used as a database interface format by the European Space Agency (ESA). Not yet used in the UK.

3. Which is the right data exchange format to adopt, if any?

Here we examine seven existing data formats and evaluate which is the most useful/user friendly format to adopt. Four suitable data formats have been identified from those examined. They are suitable because for any fireball, all essential metadata and point observation data is contained in a single data file. The identified suitable formats are:

[4] See WGN38:1 (2010), pp 10-24

- **UFOAnalyzer "A.XML"** data format, if generalised. Widely used by amateurs in the UK, Japan and Western Europe (for an example of this format, see Appendix 1).

- **Virtual Meteor Observatory (VMO)**. Not used by any camera systems. MetRec files are converted into this format to enable archiving by the ESA (for an example of this format, see Appendix 2).

- **AllSkyCams**. Closely associated with the American Meteor Society and is the format which is accepted by the AMS/IMO database (for an example of this format, see Appendix 3).

- **Desert Fireball Network (DFN)**. The DFN network has the largest coverage (by area) of any fireball system internationally (for an example of this format, see Appendix 4).

3.1 Evaluation of the UFOAnalyzer "A.XML" format.

Some advantages and disadvantages of the UFOAnalyzer "A.XML" format are as follows:

Advantages:
- Currently, can be read using standard XML parsing routines in Python or other languages.
- Currently can be written by similar routines.
- Can already be read by some pipeline programs.
- Compact, so easily read by humans and/or printed.

Disadvantages:
- Individual point observations are not explicitly timestamped
- The .XML file format is deeply nested, which is unnecessary and adds a burden to reading and writing.
- XML is increasingly used only in web interfaces rather than for data encoding.

It should be noted that the "A.XML" data is not essential for analysis using the UFO software suite, so there is no need for backward compatibility. If data needs to be sent to UFOAnalyzer, the easily-produced "R91.CSV" format can be used. However, the "R91.CSV" format does not contain enough data to be acceptable as a fireball data exchange format in other circumstances.

Changes (such as de-nesting of the XML format) would be desirable, but the most important generalisation needed by the "A.XML" format is addition of timing information to each point observation. Currently this can be inferred from other data in the file, though in a manner that can be unclear if interlaced video is used.

3.2 Evaluation of the VMO format

Some advantages and disadvantages of the VMO XML format are as follows:

Advantages:
- Currently, can be read using standard XML parsing routines.
- Currently can be written by similar routines.
- Was agreed by many IMO members in 2010.

Disadvantages:
- Very verbose, so is hard for humans to read or print out.
- Agreed ten years ago, but not used by any camera systems.
- XML is increasingly used only in web interfaces rather than for data encoding.

3.3 Evaluation of the AllSkyCams format

Some advantages and disadvantages of the AllSkyCams JSON format are as follows:

Advantages:
- Currently, can be read using standard JSON parsing routines.
- Currently can be written by similar routines.
- Is used by the AMS/IMO databases and by the increasingly popular American AllSkyCams camera system.

Disadvantages:
- Very verbose, so is hard for humans to read or print out.

3.4 Evaluation of the DFN format

Some advantages and disadvantages of the DFN format are:

Advantages:
- Compact, so easily read by humans and/or printed.
- In a native Python format (i.e. an Astropy table), so very easy to read/write.
- Simple enough to be read/written easily line-by-line if necessary, e.g. by non-Python systems.
- Used by the globally largest fireball network

Disadvantages:
- Used in the UK, but not yet widely used elsewhere in Europe or in America.

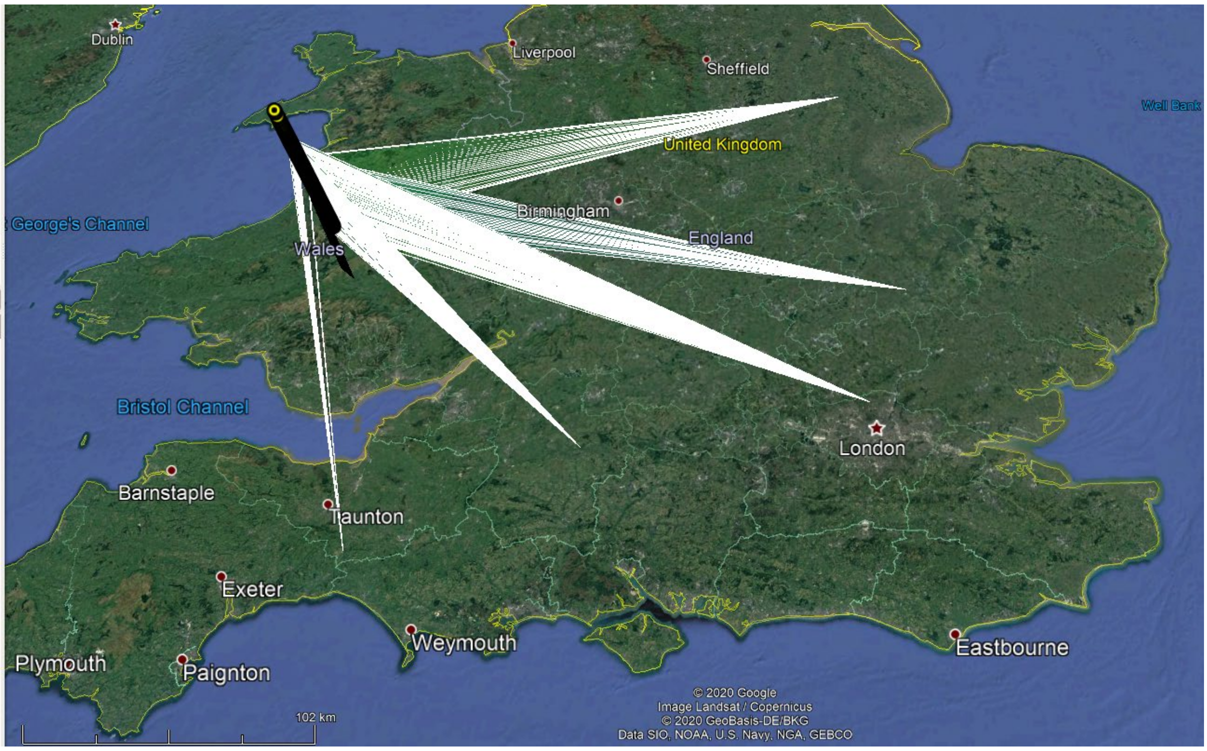

Figure 3: Triangulation of the 7th April 2020 fireball using observations from UKFN (Lincoln and Mullard stations, using Desert Fireball Network cameras) and UKMON (East Barnet, Wilcot and Chard, using UFOCapture systems), made compatible with the converter script described in Section 4 below.

3.5 Recommendation for a Fireball Data Exchange Standard

Writing the converter program (described in section 4 below) gave the authors experience of reading, writing and manipulating the various data formats. The most difficult to deal with were those with data spread across two files which were each in arbitrary formats which needed to be read line-by-line.

Manageable but not optimal were the formats which could easily be parsed as XML or JSON files but which then resulted in complex and nested data structures. In order to take advantage of the easy read-write routines, the internal data structures needed to be matched to the file structures and this created arbitrary complexity which then needed to be unpicked.

By far the simplest to read, write and manipulate was the Astropy table format used by Desert Fireball Network. This has a flat data structure with no redundant nesting or complexity. The read/write routines are standard and resilient.

The authors propose a standard which is as close as possible to the Desert Fireball Network data file format, except that data which is unique to DFN and mandatory when reading DFN data files (e.g. the metadata item “event_codename” and point observation data items such as “err_minus_azimuth”) should not be required; RA and Dec should be mandatory and astronomical magnitude should be calculated and recorded.

A list of items included in the “Standard” format is set out in Tables 1 and 2 in section 1.2 above. For an example of the Standard format, see Appendix 5.

4. A New Converter Program

Here we present a new converter script that can convert fireball data files to any agreed standard format. Functionality of the script is summarised in the diagram below:

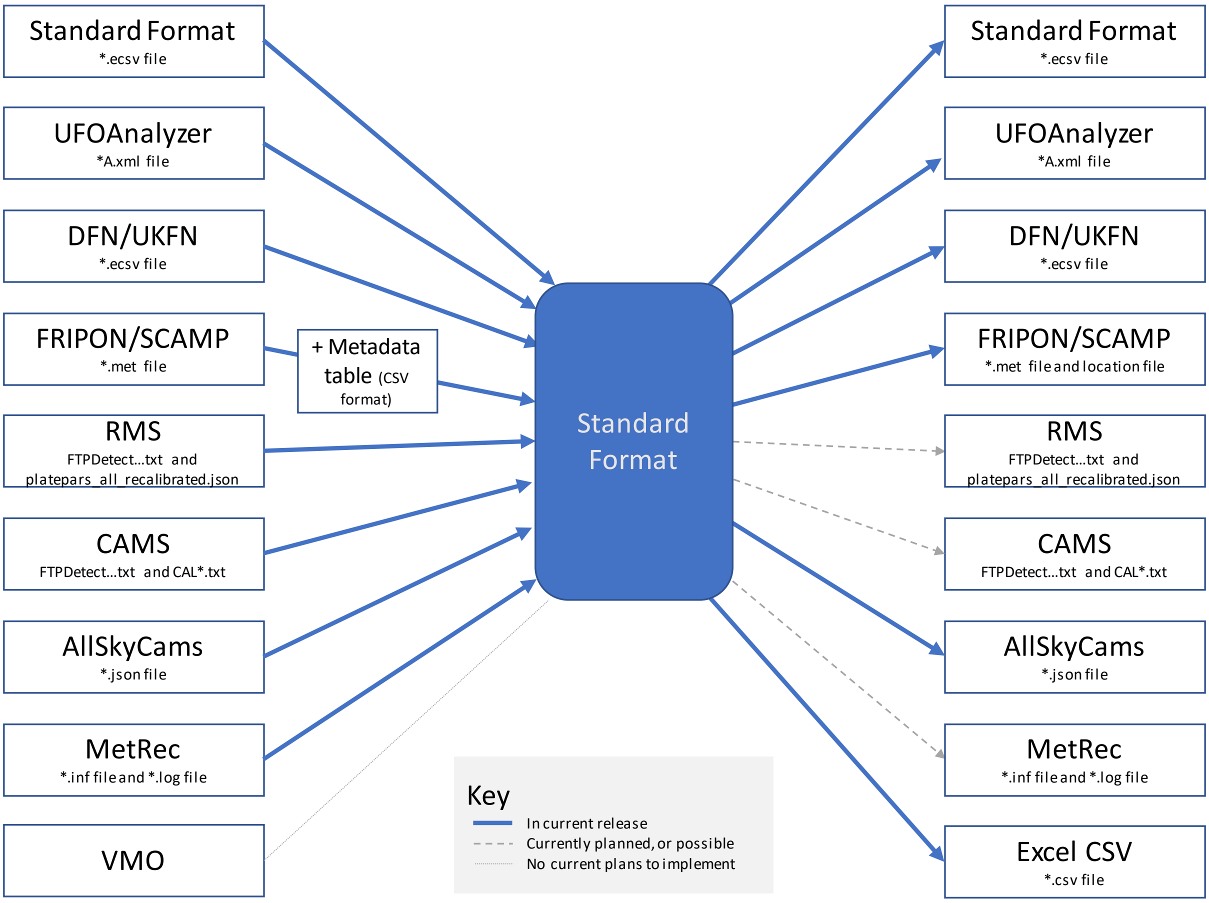

Figure 4: Data flow as currently implemented in the converter script. As the input files from RMS and CAMS systems will usually contain a full night's observations (i.e. N meteors, where N may be greater than 1) and not just the fireball of interest, there will often be multiple output files for each input file.

Based on a Jupyter notebook kindly provided by Hadrien Devillepoix of the Desert Fireball Network in Australia, the converter was further developed by SCAMP (to add the UFO, FRIPON, Standard Form, Excel CSV and AllSkyCams functionality) and by Nicholas Pochinkov of Trinity College Dublin and the Astronomy & Astrophysics Section, Dublin Institute for Advanced Studies, Republic of Ireland (who added the RMS, CAMS and MetRec functionality and the multi-meteor capability). The script makes extensive use of astrometry functions written by Denis Vida for the GMN system, including routines for RA/Dec to Alt/Az conversion, precession and great circle fitting. These functions were accessed at https://github.com/CroatianMeteorNetwork/RMS.

The converter script is also available, at https://github.com/SCAMP99/converter.

Whilst it is feasible to produce a converter for multiple formats as an interim measure or for a single static format (such as UFOAnalyzer's "A.XML") for a long period, it is not practicable over the long term to maintain a reliable converter program for the multiplicity of file formats that exist now or may exist in the future. A rigid converter script creates a bottleneck and a perpetual maintenance issue, whereas a data exchange standard places the burden of compliance on those creating and maintaining the individual camera systems.

5. Remaining problems that a common format does not solve

Issues that a common format does not solve include - becoming aware that an event has occurred, data quality problems caused by combining amateur data with professional systems, whether to share data between networks in the first place, and whether to make data public. Each of these is touched upon below:

5.1 Becoming aware that an event has occurred.

In the UK, public reports are often the first indication that a fireball event has occurred. This often is not enough; for example the 11th May 2020 fireball event (see Figure 2 above) was captured by one or two stations of each of the five UK fireball networks, but this was not known to each of the networks until six weeks later.

Internationally, currently alerts are raised by several independent systems[5] – NASA NEO has a system and ESA is using a system called NEMO, both of which scan social media for reports; another main entry point is the AMS/IMO fireball report webpage. All systems have their own format, so exchanging information automatically would need significant work. The FRIPON/SCAMP network has its own internal notification system to find simultaneous observations of an event, as does the Desert Fireball Network.

In the UK, there are several ad-hoc systems and these will continue to be used. The further development of the AMS/IMO system is welcomed and is being supported.

5.2 Problems caused by combining amateur data with professional systems

Large professional networks such as FRIPON or Desert Fireball Network deploy a limited range of hardware and software and can control the quality of their hardware, timing data and astrometry. By contrast, amateur equipment can be badly-calibrated and can have substantial timing errors caused by computer clock drift.

More positively, comparing observations from diverse sources may highlight systemic errors in the non-amateur camera systems. Sharing primary image data further exposes all systems to external evaluation, to the (eventual) benefit of all parties.

Being able to exchange data means that you have the option to examine, evaluate and perhaps use it. It doesn't mean you must use it.

5.3 Whether to share data and/or to make data public

Large professional fireball networks are expensive to establish and run. There should be no expectation that they will give out detailed processed data routinely or make data public other than in published papers. Where there are multiple overlapping networks (such as in the UK), exchange of data between networks makes finding a meteorite more likely, and is also likely to provide a better orbital estimate. It is also a useful discipline – if two networks observe the same meteor but (even allowing for observational uncertainty) don't calculate the same orbit, then it is worth finding out why.

Establishing a data exchange format allows data to be exchanged efficiently and rapidly with trusted partners if and when the network wants to do so.

[5] Private meeting minutes, 15th June 2020.

6. Conclusion and Recommendation

Meteorite recovery is inhibited in countries where multiple incompatible fireball camera systems are used. Adopting a common file format that could be read by each system would greatly assist in the observation and recovery of new meteorite falls with orbits.

There are several candidates for such a format. Based on our evaluation, the best format to use is very similar to the Desert Fireball Network's ".ecsv" Astropy table format. This is because on balance it is the easiest to read, write and to manipulate once read.

We would invite all camera system developers to comment on this proposed format, and for the IMO or IAU to either adopt this format or to propose a better alternative format.

References

[1] Ceplecha, Z. (1987) Geometric, Dynamic, Orbital and Photometric Data on Meteoroids From Photographic Fireball Networks. *Bulletin of the Astronomical Institutes of Czechoslovakia* 38, 222.
[2] Devillepoix, H. A. R., Cupák, M., Bland, P. A., Sansom, E. K., Towner, M. C., Howie, R. M., ... & Benedix, G. K. (2020). A Global Fireball Observatory. arXiv preprint arXiv:2004.01069.
[3] Sansom, E. K., Rutten, M. G., Bland, P. A. (2017). Analyzing Meteoroid Flights Using Particle Filters. *The Astronomical Journal* 153, 87-96.
[4] SonotaCo (2009). "A meteor shower catalog based on video observations in 2007-2008". WGN, Journal of the International Meteor Organization, 37, 55–62.
[5] Vida, D., Mazur, M. J., Segon, D., Zubovic, D., Kukic, P., Parag, F., & Macon, A. (2018). First results of a Raspberry Pi based meteor camera system. *WGN, the Journal of the International Meteor Organisation* 46(2), 71-78.
[6] Bertin, E., Arnouts, S. (1996.) SExtractor: Software for source extraction. *Astronomy and Astrophysics Supplement Series* 117, 393-404.
[7] Jenniskens, P., Gural, P. S., Dynneson, L., Grigsby, B. J., Newman, K. E., Borden, M., Koop, M., Holman, D. (2011). CAMS: Cameras for Allsky Meteor Surveillance to establish minor meteor showers. *Icarus* 216(1), 40-61.
[8] Barentsen, G., Arlt, R., Koschny, D., … & Zoladek, P. (2010). The VMO file format. I. Reduced camera meteor and orbit data. *WGN, the Journal of the International Meteor Organisation* 38(1), 10-24.
[9] Bennett, G.G. (1982). "The Calculation of Astronomical Refraction in Marine Navigation". Journal of Navigation. 35 (2): 255–259.
[10] Vida, D., Gural, P., Brown, P., Campbell-Brown, M., Wiegert, P. (2020). Estimating trajectories of meteors: an observational Monte Carlo approach - I. Theory. MNRAS, Preprint 23 April 2020.

Appendices

Appendix 1 – Sample UFOAnalyzer format
Appendix 2 – Sample Virtual Meteor Observatory (VMO) format
Appendix 3 – Sample AllSkyCams format
Appendix 4 – Sample Desert Fireball Network format
Appendix 5 – Sample "Standard" data format

Appendix 1 – The existing UFOAnalyzer format

Metadata is listed in the top two sections, while point observation data is listed line-by-line below. An extension of this format could:

- put an unambiguous time-stamp on each line of point data,
- reduce the nesting of the XML coding,
- allow fewer or more columns of point observation data to be present, or fewer or more metadata items and in any order.


```
<?xml version="1.0" encoding="UTF-8" ?>
<ufoanalyzer_record version ="200"
        clip_name="M20200407_035641_EastBarnet_NW" o="1" y="2020" mo="4"
        d="7" h="3" m="56" s="41.450001"
        tz="0" tme="1.000000" lid="EastBarnet" sid="NW"
        lng="2.169200" lat="50.637402" alt="86.000000" cx="720"
        cy="576" fps="25.000000" interlaced="1" bbf="0"
        frames="121" head="30" tail="30" drop="-1"
        dlev="43" dsize="2" sipos="5" sisize="9"
        trig="1" observer="User Name" cam="Watec_902H2_Ultimate" lens="Tamron_GL412IRDD"
        cap="Dazzle_DVD_HD" u2="224" ua="243" memo=""
        az="298.953644" ev="31.447386" rot="-2.832725" vx="64.745132"
        yx="0.918104" dx="-17.050308" dy="39.190449" k4="0.000000"
        k3="-0.017841" k2="0.001094" atc="58.299999" BVF="-0.300000"
        maxLev="255" maxMag="0.636000" minLev="80" mimMag="1.891000"
        dl="58" leap="40" pixs="1707" rstar="26"
        ddega="0.020532" ddegm="0.044548" errm="0.174812" Lmrgn="5"
        Rmrgn="5" Dmrgn="5" Umrgn="5">
       <ua2_objects>
<ua2_object
        fs="64" fe="178" fN="115" sN="105"
        sec="2.280000" av="5.669521" pix="1697" bmax="255"
        bN="27" Lmax="12178.500000" mag="-3.561634" cdeg="0.030362"
        cdegmax="0.224031" io="3" raP="61.588936" dcP="33.313961"
        av1="4.953533" x1="172.202469" y1="200.227478" x2="147.087616"
        y2="76.042046" az1="282.239838" ev1="18.227255" az2="281.346924"
        ev2="6.776121" azm="281.962646" evm="14.787333" ra1="166.860901"
        dc1="21.839781" ra2="159.931808" dc2="12.449558" ram="164.702042"
        dcm="19.044653" class="spo" m="0" dr="-1.000000"
        dv="-1.000000" Vo="-1.000000" lng1="-4.182658" lat1="52.104084"
        h1="100.000000" dist1="299.423035" gd1="280.094147" azL1="-1.000000"
        evL1="-1.000000" lng2="-999.000000" lat2="-999.000000" h2="-1.000000"
        dist2="-1.000000" gd2="-1.000000" len="0.000000" GV="0.000000"
        rao="224.512238" dco="55.490002" Voo="30.740000" rat="222.530472"
        dct="55.236355" memo="">
       <ua2_objpath>
<ua2_fdata2 fno=" 64" b="189" bm="000" Lsum="   393.5" mag="+0.16" az=" 282.2609209" ev="  18.2187545" ra=" 166.8385898" dec=" +21.8464019"></ua2_fdata2>
<ua2_fdata2 fno=" 67" b="188" bm="000" Lsum="   414.1" mag="+0.11" az=" 282.2433474" ev="  17.9072948" ra=" 166.6336298" dec=" +21.5993546"></ua2_fdata2>
<ua2_fdata2 fno=" 68" b="196" bm="000" Lsum="   476.7" mag="-0.04" az=" 282.2396071" ev="  17.8011475" ra=" 166.5622027" dec=" +21.5164877"></ua2_fdata2>
<ua2_fdata2 fno=" 69" b="255" bm="001" Lsum="   626.5" mag="-0.34" az=" 282.2324171" ev="  17.6988598" ra=" 166.4962397" dec=" +21.4343797"></ua2_fdata2>
<ua2_fdata2 fno=" 70" b="255" bm="001" Lsum="   712.3" mag="-0.48" az=" 282.2343855" ev="  17.5904053" ra=" 166.4189309" dec=" +21.3532347"></ua2_fdata2>
<ua2_fdata2 fno=" 71" b="255" bm="001" Lsum="   828.6" mag="-0.64" az=" 282.2128720" ev="  17.5080970" ra=" 166.3782081" dec=" +21.2773652"></ua2_fdata2>
<ua2_fdata2 fno=" 72" b="255" bm="002" Lsum="   742.4" mag="-0.52" az=" 282.2106446" ev="  17.4166493" ra=" 166.3161715" dec=" +21.2064861"></ua2_fdata2>
<ua2_fdata2 fno=" 73" b="255" bm="002" Lsum="   745.2" mag="-0.53" az=" 282.2070630" ev="  17.3037306" ra=" 166.2403007" dec=" +21.1184170"></ua2_fdata2>
<ua2_fdata2 fno=" 74" b="255" bm="002" Lsum="   937.8" mag="-0.78" az=" 282.1952818" ev="  17.2129824" ra=" 166.1863254" dec=" +21.0420929"></ua2_fdata2>
<ua2_fdata2 fno=" 75" b="255" bm="001" Lsum="  1053.4" mag="-0.90" az=" 282.2026761" ev="  17.1198237" ra=" 166.1158059" dec=" +20.9758007"></ua2_fdata2>
<ua2_fdata2 fno=" 76" b="255" bm="002" Lsum="  1012.4" mag="-0.86" az=" 282.1898748" ev="  17.0211934" ra=" 166.0572803" dec=" +20.8927964"></ua2_fdata2>
<ua2_fdata2 fno=" 77" b="255" bm="002" Lsum="  1268.9" mag="-1.11" az=" 282.1645078" ev="  16.8874645" ra=" 165.9842922" dec=" +20.7752431"></ua2_fdata2>
<ua2_fdata2 fno=" 78" b="255" bm="002" Lsum="  1655.3" mag="-1.39" az=" 282.1630548" ev="  16.7758803" ra=" 165.9081290" dec=" +20.6893414"></ua2_fdata2>
<ua2_fdata2 fno=" 79" b="255" bm="003" Lsum="  1852.4" mag="-1.52" az=" 282.1438145" ev="  16.6720709" ra=" 165.8513055" dec=" +20.5983011"></ua2_fdata2>
       </ua2_objpath>
</ua2_object>
       </ua2_objects>
</ufoanalyzer_record>
```

Appendix 2 – The Virtual Meteor Observatory (VMO) format

This example is taken from WGN, the Journal of the International Meteor Organisation 38:1 (2010), p 12. Please note that in this example:

- The observatory location and observer's e-mail address have been altered.
- Only two points of point observation data are included, compared with 14 points in Appendices 1 and 3. While perfectly adequate for machine reading at the moment, the layout of point observation data is verbose.
- This data file can be read using standard parsing routines in Python.


```
<?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@domain-name.int</email>
  </observer>

  <location>
        <location_code>NLNOOR</location_code>
        <name>Noordwijkerhout</name>
        <country_code>NL</country_code>
        <lon>2.491112</lon>
        <lat>50.265282</lat>
        <height>86</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_dee>72.38500</pos_dee>
                <e_mag>0.42</e_mag>
                <e_pos_ra>0.0321</e_pos_ra>
                <e_pos_dee>0.0321</e_pos_dee>
          </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_dee>72.09010</pos_dee>
                <e_mag>0.42</e_mag>
```

```
                <e_pos_ra>0.0321</e_pos_ra>
                <e_pos_dee>0.0321</e_pos_dee>
        </pos>

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

Appendix 3 – The AllSkyCams JSON format

Please note that in this example:

- The observatory location has been altered.
- Only two points of point observation data are included, compared with 14 points in Appendices 1 and 4. While perfectly adequate for machine reading, the layout of point observation data is verbose.
- Only two calibration stars are included, again to save space.
- This data file can be read and written using standard parsing routines in Python.


```
{
   "info": {
      "station": "AMS1",
      "device": "010002",
      "org_hd_vid": "/mnt/ams2/meteors/2020_07_09/2020_07_09_01_27_16_000_010002-trim-453.mp4",
      "org_sd_vid": "/mnt/ams2/meteors/2020_07_09/2020_07_09_01_27_18_000_010002-trim-0403.mp4",
      "hd_vid": "/mnt/ams2/meteor_archive/AMS1/METEOR/2020/07/09/2020_07_09_01_27_18_000_010002-trim-0403-HD.mp4",
      "sd_vid": "/mnt/ams2/meteor_archive/AMS1/METEOR/2020/07/09/2020_07_09_01_27_18_000_010002-trim-0403-SD.mp4"
   },
   "frames": [
      {
         "fn": 53,
         "x": 737,
         "y": 648,
         "w": 13,
         "h": 13,
         "dt": "2020-07-09 01:27:36.240",
         "az": 52.23007932906461,
         "el": 32.02976977305471,
         "ra": 315.9977463610816,
         "dec": 47.57334483668456
      },
      {
         "fn": 54,
         "x": 735,
         "y": 652,
         "w": 12,
         "h": 13,
         "dt": "2020-07-09 01:27:36.280",
         "az": 52.155541677346186,
         "el": 31.85004313932977,
         "ra": 316.2784863883492,
         "dec": 47.5529425379891
      },
   ],
   "report": {
      "classify": {
         "px_dist": 115.48592987892508,
         "ang_sep_px": 4.811913744955212,
         "ang_vel_px": 120.2978436238803,
         "ang_sep_deg": 8.3406504912557,
         "ang_vel_deg": 8.688177595058022,
         "bad_items": [],
         "meteor_yn": "Y",
         "cm": 25,
         "unq_perc": 0.96,
         "unq": "24/25",
         "unqkeys": "{'737.648': 1, '735.652': 1, '732.656': 1, '730.661': 1, '727.667': 1, '725.670': 1, '722.675': 1, '721.676': 1, '717.683': 1, '716.687': 1, '713.691': 1, '710.697': 1, '708.698': 1, '704.706': 1, '702.711': 1, '700.715': 1, '697.721': 1, '695.725': 1, '693.727': 1, '690.733': 1, '688.738': 1, '684.742': 1, '682.746': 1, '681.749': 1}",
         "neg_int_perc": 0,
         "segs": [
            0,
            4,
            4,
            5,
            6,
            3,
            5,
            1,
            8,
            3,
            4,
            6,
            1,
            8,
            5,
            4,
            6,
            4,
            2,
```

```
            6,
            5,
            5,
            4,
            3,
            0
         ],
         "bad_seg_perc": 0.16666666666666666
      },
      "meteor_yn": "Y",
      "elp": 25,
      "min_max_dist": 115.48592987892508,
      "dist_per_elp": 4.619437195157003,
      "moving": "moving",
      "dir_test_perc": 1.96,
      "max_cm": 25,
      "elp_max_cm": 1.0,
      "max_fns": 25,
      "neg_perc": 0.0,
      "avg_line_res": 0.36930687630770714,
      "obj_class": "meteor",
      "bad_items": [],
      "x_dir_mod": 1,
      "y_dir_mod": -1,
      "score": 9
   },
   "sync": {
      "sd_ind": 53,
      "hd_ind": 53
   },
   "calib": {
      "dt": "2020_07_09_01_27_16_000",
      "device": {
         "poly": {
            "x_fwd": [
               7.307123718090265e-05,
               -0.00012976403874331505,
               -0.00010386191622264846,
               1.8921573731620332e-05,
               -2.431782513070777e-05,
               -2.3549585900829807e-05,
               1.5222071363595274e-08,
               -1.0866345090093761e-07,
               1.0112572127462236e-08,
               -5.351836028084683e-10,
               -3.080649098675653e-05,
               6.075186493635432e-06,
               2.3113305657592207e-05,
               0.00023901999412703214,
               0.00020930533071559815
            ],
            "y_fwd": [
               0.00012642872564281747,
               -7.851629706650122e-05,
               0.0001626357250317206,
               -6.392144301424999e-06,
               4.787373857172613e-06,
               1.3741827197385441e-05,
               3.254636225657236e-08,
               2.6120706218196875e-07,
               8.259400905439808e-08,
               1.9301425531391468e-07,
               -0.00011943856370776716,
               -1.614268384367053e-05,
               8.277440915533455e-06,
               0.0002029443857813952,
               0.00023730596159879445
            ],
            "x": [
               -0.0004595308185151854,
               -0.0009323451306861282,
               -0.0004174878438287091,
               1.7868981574334697e-05,
               -2.0428312720762725e-05,
               -2.9025715573477365e-05,
               8.144291091678914e-09,
               -1.0079713686669032e-07,
               1.22924063482233e-08,
               4.2046058121837725e-08,
               -2.7108893781948726e-05,
               -8.47466556185703e-06,
               0.0005318054219418538,
               0.0006907655633423915,
               0.0005337125911285379
            ],
            "y": [
```

```
            0.0011843099889472064,
            -0.0006122417009754074,
            0.0008409774959545716,
            -3.7137585156919347e-06,
            6.0276650826983415e-06,
            1.5387811799335965e-05,
            3.581876601336122e-08,
            2.6287430797051863e-07,
            9.538763244192371e-08,
            2.0320710246139012e-07,
            -0.00012409494924377418,
            -1.6982763506623343e-05,
            -0.0007286509172075737,
            -0.0003892035309566319,
            0.0001750722903087507
          ]
        },
        "center": {
          "az": 63.39396762920722,
          "el": 37.325009053782665,
          "ra": "303.850125",
          "dec": "41.294777777777774"
        },
        "alt": "100",
        "lat": "19.580000",
        "lng": "-26.585555",
        "angle": 294.24282584963674,
        "scale_px": 156.24067597167203,
        "org_file": "/mnt/ams2/cal/freecal/2019_07_21_06_49_41_000_010002/2019_07_21_06_49_41_000_010002-stacked-calparams.json",
        "total_res_px": 2.1507806870833543,
        "total_res_deg": 0.09334428567131126
      },
      "stars": [
        {
          "name": "Vega",
          "mag": 0.0,
          "ra": 279.2346,
          "dec": 38.7836,
          "dist_px": 4.841036034281386,
          "intensity": 0,
          "i_pos": [
            1137,
            128
          ],
          "cat_dist_pos": [
            1139,
            131
          ],
          "cat_und_pos": [
            1139,
            131
          ]
        },
        {
          "name": "Deneb",
          "mag": 1.2,
          "ra": 310.3579,
          "dec": 45.2803,
          "dist_px": 9.88320635550075,
          "intensity": 0,
          "i_pos": [
            825,
            588
          ],
          "cat_dist_pos": [
            828,
            597
          ],
          "cat_und_pos": [
            828,
            597
          ]
        },
      ],
      "img_dim": [
        1920,
        1080
      ]
    }
}
```

Appendix 4 – The Desert Fireball Network format

This is the same meteor observation as in Appendix 1, converted to Desert Fireball Network using the Python script described above. Please note that:

- Metadata is listed in the top section and would normally be much more extensive. It is brief here because this example results from a conversion of a UFOAnalyzer file.
- Point observation data is listed line-by-line below. As in the example in Appendix 1, many rows of point data have been deleted so that the example fits on a single page, and some floating-point numbers have been rounded so that lines also fit on the page.

```
# %ECSV 0.9
# ---
# datatype:
# - {name: azimuth, unit: deg, datatype: float64}
# - {name: altitude, unit: deg, datatype: float64}
# - {name: datetime, datatype: string}
# - {name: time_err_plus, unit: s, datatype: float64}
# - {name: time_err_minus, unit: s, datatype: float64}
# - {name: err_plus_azimuth, unit: deg, datatype: float64}
# - {name: err_minus_azimuth, unit: deg, datatype: float64}
# - {name: err_plus_altitude, unit: deg, datatype: float64}
# - {name: err_minus_altitude, unit: deg, datatype: float64}
# delimiter: ','
# meta: !!omap
# - {obs_longitude: 2.1692}
# - {obs_latitude: 50.637402}
# - {obs_elevation: 86.0}
# - {location: EastBarnet}
# - {event_codename: DN200000_00}
# - {isodate_start_obs: '2020-04-07T03:56:40.250'}
# - {telescope: NW}
# - {origin: UFOAnalyzer_Ver_224}
# - {observer: User Name}
# - {instrument: Watec_902H2_Ultimate}
# - {NAXIS1: 720}
# - {NAXIS2: 576}
# - {lens: Tamron_GL412IRDD}
# - {image_file: M20200407_035641_EastBarnet_NW.AVI}
# - {astrometry_number_stars: 26}
# schema: astropy-2.0
azimuth,altitude,datetime,time_err_plus,time_err_minus,err_plus_azimuth,err_minus_azimuth,err_plus_altitude,err_minus_altitude
282.2609209,18.2187545,2020-04-07T03:56:41.510,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.2433474,17.9072948,2020-04-07T03:56:41.570,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.2396071,17.8011475,2020-04-07T03:56:41.590,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.2324171,17.6988598,2020-04-07T03:56:41.610,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.2343855,17.5904053,2020-04-07T03:56:41.630,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.212872,17.508097,2020-04-07T03:56:41.650,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.2106446,17.4166493,2020-04-07T03:56:41.670,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.207063,17.3037306,2020-04-07T03:56:41.690,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.1952818,17.2129824,2020-04-07T03:56:41.710,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.2026761,17.1198237,2020-04-07T03:56:41.730,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.1898748,17.0211934,2020-04-07T03:56:41.750,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.1645078,16.8874645,2020-04-07T03:56:41.770,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.1630548,16.7758803,2020-04-07T03:56:41.790,0.1,0.1,0.0166,0.0166,0.0166,0.0166
282.1438145,16.6720709,2020-04-07T03:56:41.810,0.1,0.1,0.0166,0.0166,0.0166,0.0166
```

Appendix 5 – The "Standard" format

This is the same meteor observation as in Appendix 1 and 4, converted to Standard format using the Python script described above. Please note that point observation data is listed line-by-line below. As in the example in Appendix 1, many rows of point data have been deleted so that the example fits on a single page, and some floating-point numbers have been rounded so that lines also fit on the page.

```
# %ECSV 0.9
# ---
# datatype:
# - {name: datetime, datatype: string}
# - {name: azimuth, unit: deg, datatype: float64}
# - {name: altitude, unit: deg, datatype: float64}
# - {name: ra, unit: deg, datatype: float64}
# - {name: dec, unit: deg, datatype: float64}
# - {name: mag, datatype: float64}
# - {name: x_image, datatype: float64}
# - {name: y_image, datatype: float64}
# delimiter: ','
# meta: !!omap
# - {obs_latitude: 51.637402}
# - {obs_longitude: -0.1692}
# - {obs_elevation: 86.0}
# - {origin: UFOAnalyzer_Ver_224}
# - {location: EastBarnet}
# - {telescope: NW}
# - {camera_id: EastBarnet_NW}
# - {observer: Jim_Rowe}
# - {instrument: Watec_902H2_Ultimate}
# - {cx: 720}
# - {cy: 576}
# - {image_file: M20200407_035641_EastBarnet_NW.AVI}
# - {isodate_start_obs: '2020-04-07T03:56:40.250'}
# - {isodate_mid_obs: '2020-04-07T03:56:42.590'}
# - {exposure_time: 4.68}
# - {astrometry_number_stars: 26}
# - {photometric_zero_point: 1.891}
# - {photometric_zero_point_uncertainty: 0.0}
# - {lens: Tamron_GL412IRDD}
# - {obs_az: 298.953644}
# - {obs_ev: 31.447386}
# - {obs_rot: -2.832725}
# - {fov_horiz: 64.745132}
# - {fov_vert: 0.0}
# schema: astropy-2.0
datetime,azimuth,altitude,ra,dec,mag,x_image,y_image
2020-04-07T03:56:41.510,282.2609209,18.2187545,166.8385898,21.8464019,0.16,0.0,0.0
2020-04-07T03:56:41.570,282.2433474,17.9072948,166.6336298,21.5993546,0.11,0.0,0.0
2020-04-07T03:56:41.590,282.2396071,17.8011475,166.5622027,21.5164877,-0.04,0.0,0.0
2020-04-07T03:56:41.610,282.2324171,17.6988598,166.4962397,21.4343797,-0.34,0.0,0.0
2020-04-07T03:56:41.630,282.2343855,17.5904053,166.4189309,21.3532347,-0.48,0.0,0.0
2020-04-07T03:56:41.650,282.212872,17.508097,166.3782081,21.2773652,-0.64,0.0,0.0
2020-04-07T03:56:41.670,282.2106446,17.4166493,166.3161715,21.2064861,-0.52,0.0,0.0
2020-04-07T03:56:41.690,282.207063,17.3037306,166.2403007,21.118417,-0.53,0.0,0.0
2020-04-07T03:56:41.710,282.1952818,17.2129824,166.1863254,21.0420929,-0.78,0.0,0.0
2020-04-07T03:56:41.730,282.2026761,17.1198237,166.1158059,20.9758007,-0.9,0.0,0.0
2020-04-07T03:56:41.750,282.1898748,17.0211934,166.0572803,20.8927964,-0.86,0.0,0.0
2020-04-07T03:56:41.770,282.1645078,16.8874645,165.9842922,20.7752431,-1.11,0.0,0.0
2020-04-07T03:56:41.790,282.1630548,16.7758803,165.908129,20.6893414,-1.39,0.0,0.0
2020-04-07T03:56:41.810,282.1438145,16.6720709,165.8513055,20.5983011,-1.52,0.0,0.0
```