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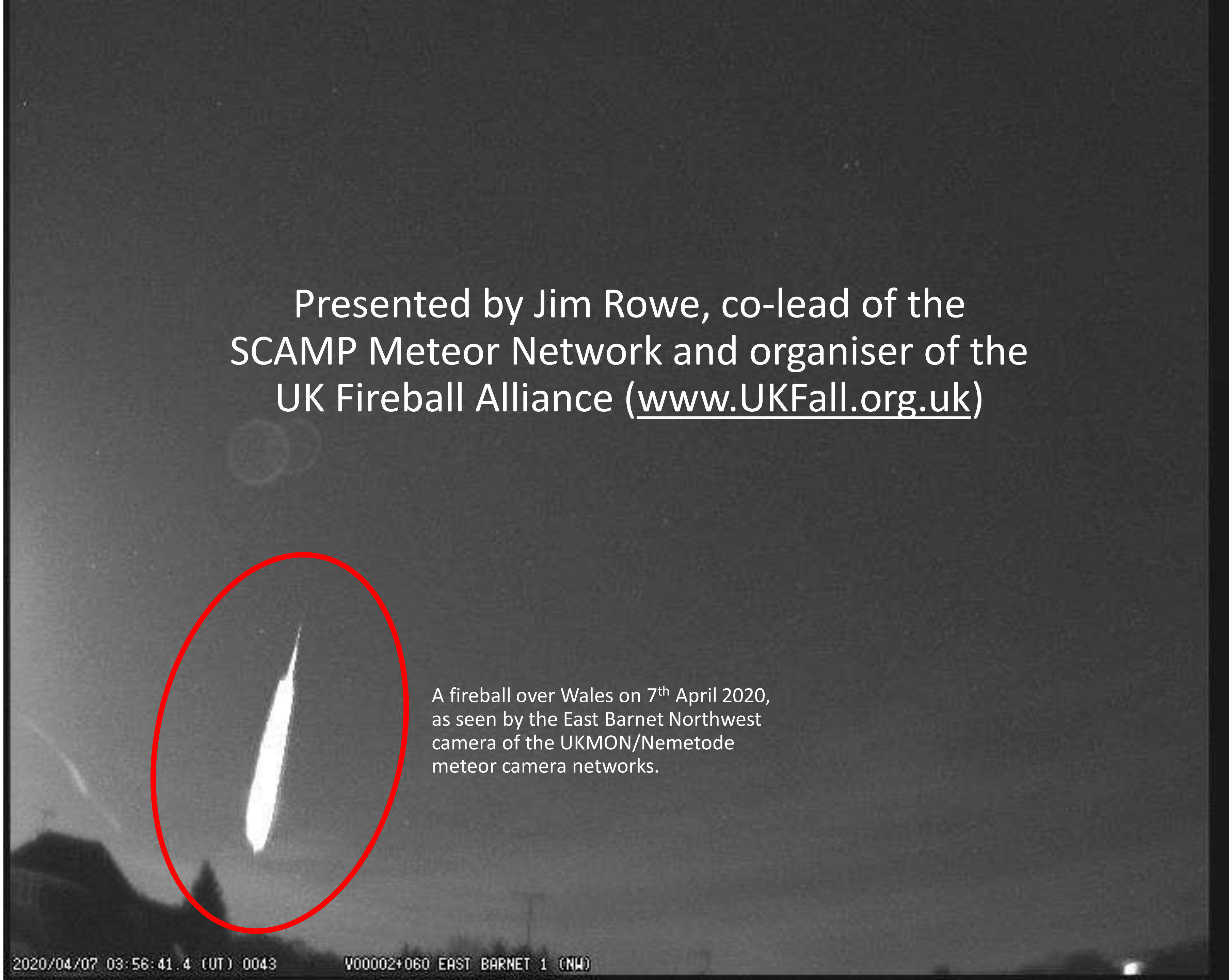
EPSC2020

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



Presented by Jim Rowe, co-lead of the SCAMP Meteor Network and organiser of the UK Fireball Alliance (www.UKFall.org.uk)

A fireball over Wales on 7th April 2020, as seen by the East Barnet Northwest camera of the UKMON/Nemetode meteor camera networks.

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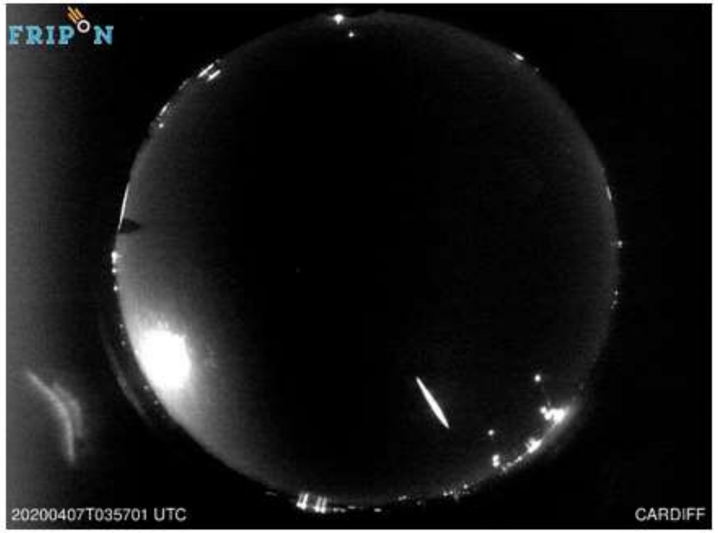

The UK has five different meteor of fireball networks, using four different hardware and software set-ups.

Here are images of the 7th April 2020 fireball from four incompatible camera systems.

How do we find a meteorite in this wonderful innovative and creative chaos?

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Here's a map of the UK networks plus nearby Irish, French and Dutch cameras.

Lots of gaps, lots of overlap, lots of incompatibility.

Lots of potential for cooperation!

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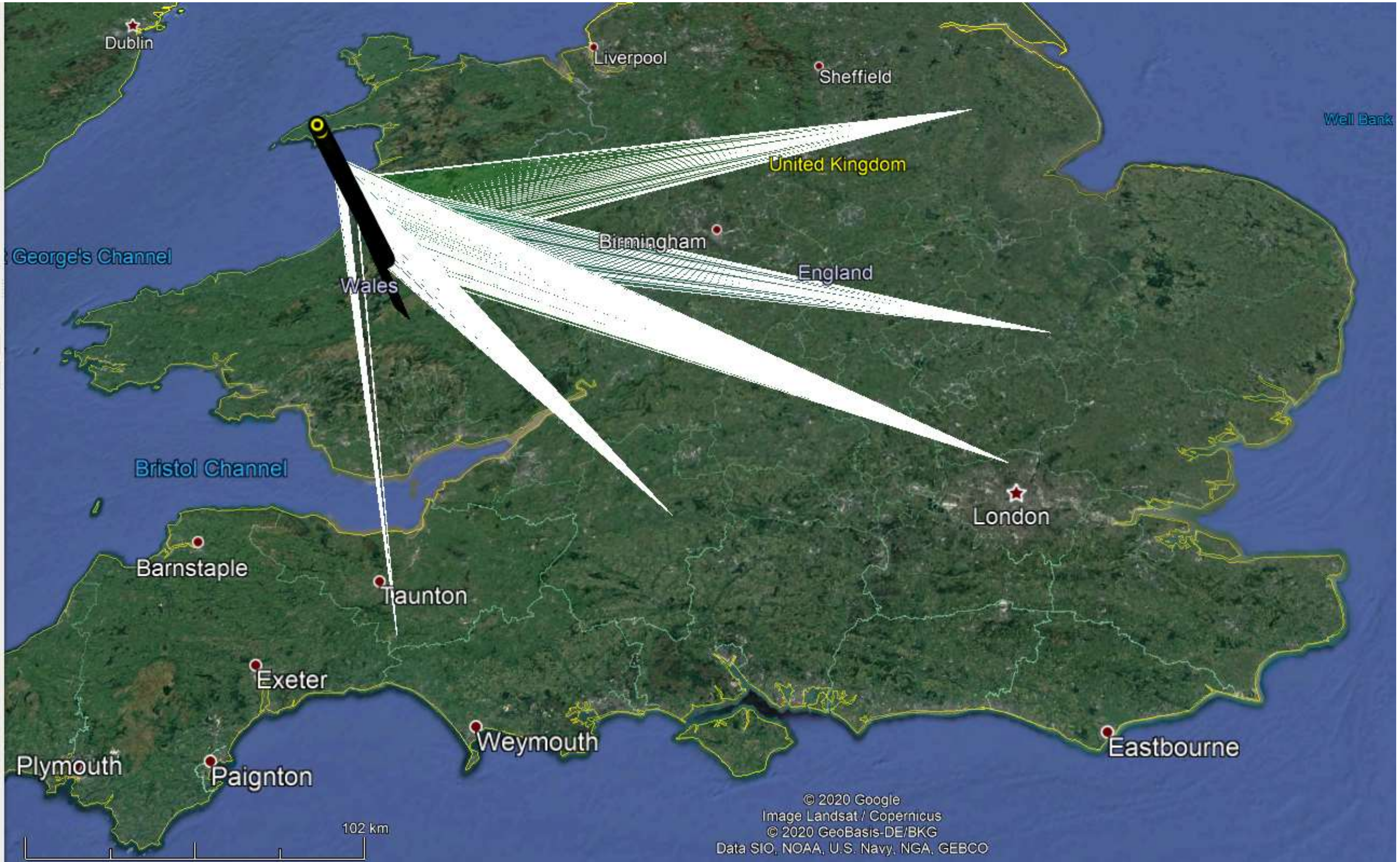

If you observe a fireball from different locations, you can determine its trajectory.

Here's what we managed to do with the fireball of 7th April 2020.

This was done despite the incompatible systems.

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Our three-step solution to the chaos and incompatibility:

1. **Coordinate -** Set up an organisation to coordinate data exchange and UK meteorite searches – now done, see www.ukfall.org.uk

2. **Convert** - Write a Python Script to convert data from one camera system to any other system – now done, see https://github.com/SCAMP99/converter

3. **Fix the future** – Agree a standard data interchange standard for fireball camera systems. **That's today's subject.**

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1. **Coordinate -** Set up an organisation to coordinate data exchange and UK meteorite searches – now done, see www.ukfall.org.uk

Done in December 2018 – UKFall founder members are: Dr Katie Joy, Dr Luke Daly, Dr Ashley King, Dr Jana Horák, Dr Apostolos Christou, Sarah McMullan, Richard Kacerek, Peter Campbell-Burns and Jim Rowe.

Affiliated to the Geologists' Association.

Organiser – Jim Rowe. Treasurer – Luke Daly.

Luke will talk more about UKFall in another presentation today, so I will move on.

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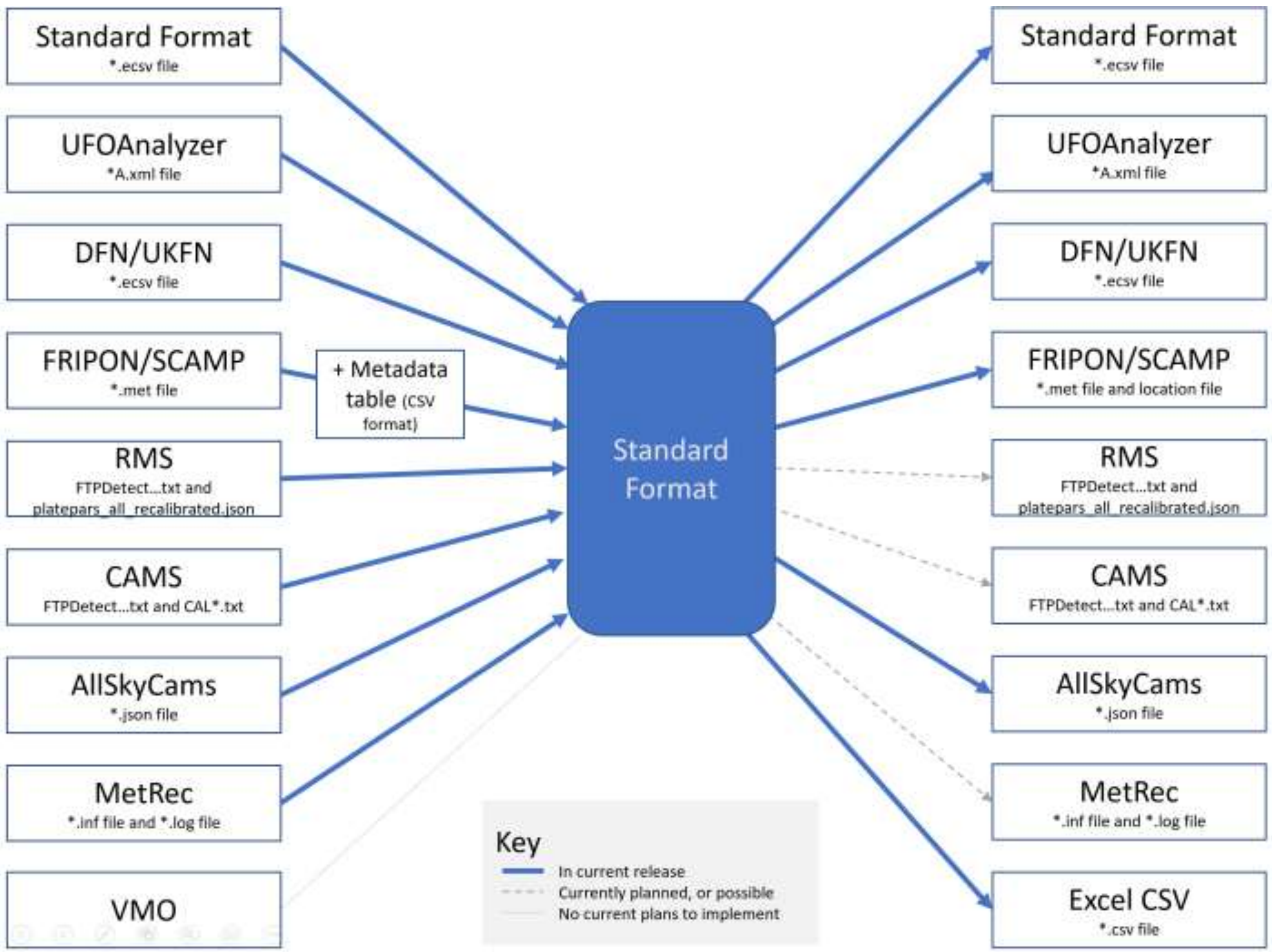
2. **Convert** - Write a Python Script to convert data from one camera system to any other system – now done, see https://github.com/SCAMP99/converter

A schematic of UKFall's converter script, written in Python (Jupyter). It can read data from eight different fireball camera formats and write that data in six different formats.



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3. **Fix the future** – Agree a standard data interchange standard for fireball camera systems. **That's today's subject.**

From left – FRIPON/SCAMP, UKFN/DFN and UKMON/ Nemetode camera systems

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What should a standard data exchange format look like?

1. **A single text file**, so it can be exchanged without losing components
2. **Complete** - contains all necessary information about the observatory as well as the observation
3. **Human-readable**, so no machine code or "pickling"
4. **Human-intelligible**, so normal dates not Julian dates, decimal degrees not radians
5. **Machine-readable** using standard parsing and dumping routines, so no line-by-line reading or writing
6. **Already used**, ***so we're not inventing something that adds to the chaos***

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. UFOAnalyzer is widely used by amateurs in the UK, Western Europe, and Japan.
- **Global Meteor Network.** Increasingly deployed in the UK, based on Raspberry Pi cameras.
- **Desert Fireball Network (DFN)**, UK Fireball Network, Global Fireball Observatory – generates a single file with all essential and most recommended data 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** – A new, innovative system used in the US and Germany.
- **MetRec** – a system widely used in Germany and Eastern Europe with a long pedigree
- **Virtual Meteor Observatory (VMO)** – an XML multiple-meteor format used as a database interface format by the European Space Agency (ESA).

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What the seven systems record – Part 1, Metadata

Each system records a lot of information about the camera and the location, i.e. the “metadata”. The most commonly-recoded 24 pieces of Metadata are as below, and it is these 24 that are suggested for inclusion in a “Standard” data exchange format.

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 identifi	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 (de	['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]

What the systems record – Part 2, Point Observation Data

For each frame of video (or equivalent), each system records a lot of information about the meteor seen, i.e. the “point observation data”. The most commonly-recoded eight pieces of Point Observation Data are as below, and it is these eight that are suggested for inclusion in a “Standard” data exchange format.

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']

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

Four suitable data formats have been identified from the eight 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:

- **UFOAnalyzer "A.XML"** data format, if generalised
- **Virtual Meteor Observatory (VMO)**. Not used by any camera systems. MetRec files are converted into this format to enable archiving by the ESA
- **AllSkyCams**. Closely associated with the American Meteor Society and is the format which is accepted by the AMS/IMO database
- **Desert Fireball Network (DFN)**. The DFN network has the largest coverage (by area) of any fireball system

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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.


```
<?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>
```

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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.

```xml
<?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>
```

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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.


```
{
  "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",
```

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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.


```
# %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
```

Recommendation for a Fireball Data Exchange Standard

Writing the converter program gave us the following experience of reading, writing and manipulating the various data formats:

- ***Most difficult*** - data spread across two files in arbitrary formats which needed to be read line-by-line – e.g. RMS, CAMS.

- ***Manageable*** - 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 – e.g. UFO, AllSkyCams, VMO, MetRec.

- ***Easiest*** 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 DFN-specific 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. Unexpected Metadata or columns of Point Observation Data should be tolerated, as should any Metadata or column order.

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Recommendation for a Fireball Data Exchange Standard

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 DFN-specific point observation data items such as “err_minus_azimuth”) is not required
- RA and Dec are the most fundamental position descriptors and so are mandatory, and
- Astronomical magnitude should be calculated and recorded.

In other words, for a single-station fireball observation:

- The 24 Metadata items plus the eight Point Observation Data items should be assigned the variable names set out in the table above, and should be written in Astropy “Table” format, with toleration of:
    - Unexpected Metadata or unexpected Point Observation Data;
    - Non-standard Metadata or column order; and/or
    - Absence of non-essential data.


```
# %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
```

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