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► **To cite this version:**

Jérémie Vaubaillon, Pedro da Fonseca, Frederic Bouley, Youssef Younes, Gilles Fasola, et al.. The “Mobile Observation of Meteor” (MoMET) device. *Experimental Astronomy*, 2022, 10.1007/s10686-022-09863-8 . hal-03796702

HAL Id: hal-03796702

<https://hal.science/hal-03796702>

Submitted on 4 Oct 2022

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The “Mobile Observation of Meteor” (MoMET) device

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Received: 6 January 2022 / Accepted: 14 July 2022

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Abstract

Meteor shower outbursts happen every year, but cannot be observed by a single meteor camera network. In addition, bad weather might prevent the recording of such event. In order to enable the observation of meteor shower outburst, we developed a “Mobile Observation of METeor” device. It involves two suitcases for meteor double station observations. Each case includes a total of 5 cameras to maximise the scientific output. Each camera is controlled by a mini-PC (RaspBerry pi or Odroid) and runs the “RMS” software (Vida et al. 2021, MNRAS, 506, 4, 5046). The MoMET devices were successfully used to record the 2021 Arids meteor shower from Chile.

Keywords Optics · Meteors · Camera · Orbits

1 Introduction: scientific goal and specifications

1.1 Introduction to meteor science

Meteors are caused by atmospheric entry of meteoroids [22, 29]. The hypervelocity impact with atmospheric molecules mainly induces an emission of atomic lines from the meteoroid and atmosphere composition [7]. Such emission is possibly visible by naked eye and meteors are also known as “shooting stars”.

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Meteors may be organized as meteor showers, caused by the ejection of a high number of meteoroids in the interplanetary space by outgassing comets. Meteor shower may show regular activity from year to year. However shower outbursts are sometimes observed and even predicted [30, 35]. Such quite rare event are sometimes extremely spectacular, both from a scientific point of view as well as from naked eye observations and impression [9, 32].

It is worth mentioning that meteoroids are extremely hard to detect. Indeed, their typical size lies between a few tens of μm to a few m [22]. Therefore they do not efficiently scatter nor reflect the light of the Sun, in a way that make them detectable from ground based telescopes. Direct imagery of individual meteoroids were only performed by spacecraft getting extremely close to asteroid or comet nucleus [12, 15, 25, 28]. Meteorites are only a small fraction of the initial meteoroid or asteroid [29]. Meteoroid streams are known mainly thanks to meteor showers, and from a few direct Mid-infrared observations [33, 39]. In addition, meteoroids are the main component of planetesimals in the early Solar System. Their size range is typical of grain growth studies aiming to better understand planetary formation [4, 19]. Measuring the meteoroids distribution, structure, evolution and composition provides us with clues on the formation and disintegration of the very bricks of the planets, asteroids and comets. The vast majority of their (indirect) observations is performed by recording meteors, i.e. when the meteoroid is disintegrating and fragmenting at a very short distance from the observer ($\sim 100 \text{ km}$). In situ observations of meteoroids ejected by comet 67P/Churyumov-Gerasimenko have showed that both low and high density particles were detected [26, 27]. Meteor observations allow us to derive such parameters, among many others [8]. In other words, ground based observation of meteors are the easiest way to infer some properties of today planetesimals.

1.2 Scientific goals of meteor shower observations

The goal of the optical video observation of meteor showers are to derive the following [24]:

- G.1 existence of a meteoroid stream (otherwise hardly detected)
- G.2 exact location at 1 AU of a meteoroid stream
- G.3 parent body of a meteoroid stream (comet or asteroid or even interstellar)
- G.4 parent body activity
- G.5 meteoroid lifetime expectancy in the Solar System
- G.6 meteoroid formation (in the early solar system and by ejection from parent body)
- G.7 meteoroid size frequency distribution
- G.8 meteoroid composition
- G.9 meteoroid tensile strength and bulk density
- G.10 comet to asteroid link (physical and dynamical)
- G.11 dynamical origin of meteoroid streams
- G.12 age of meteoroid streams

Table 1 MoMET scientific goals and associated measurements. “# cam” refers to the minimum number of camera stations needed to perform the required measurement. The zenithal hourly rate *ZHR* is the reduced number of meteors witnessed by naked eye, but unit of time [20, 21]. “SFD” refers to “size frequency distribution” and is inferred from the meteor magnitude distribution. The references are given as examples and are by no way exhaustive (adapted from previous study by [24, 37])

Scientific Goal	Measurement	# cam	Reference
Existence & Location of meteoroid stream G.1,G.2	$ZHR = f(t)$	1	[2, 31]
Comet past activity G.4,G.7	<i>ZHR</i>	1	[34]
Meteoroid life time expectancy G.5	<i>ZHR</i> , SFD	1	[23]
Meteoroid composition G.8	Spectroscopy	1	[5]
Meteoroid tensile strength G.9	light curve, 3D-trajectory	2	[6, 8]
Origin of the outburst G.11,G.10	accurate orbit	2	[13, 41]
Parent body G.3	accurate orbit	2	[13]
Age of the meteoroid trail G.12	<i>ZHR</i> , orbit distribution	2	[1]

The observation of meteors are routinely performed for decades thanks to small, light, high sensitivity video cameras. Usually, the set up includes a camera coupled to a lens, a control computer for data acquisition and a meteor detection software [24]. Double station setup allows one to derive much more scientific parameters than single station observation (see also Table 1) [37].

1.3 Problematic

The observation of a meteor shower outburst requires the fulfillment of several constraints:

- the observer must be located where the shower is visible (the shower radiant must be above the horizon). Ideally the radiant must be as high as possible at the time of the peak of the shower outburst.
- the Sun must be set.
- the weather must be clear.
- if a double-station experiment is setup for triangulation purpose, the geometry must put the meteor trajectory as perpendicular to the 2-station baseline as possible.
- all the above must hold true for the duration of the shower (from ~ 30 min to a few hours).

In spite of the development of large meteor observation fixed stations networks [10, 11, 18, 24, 42], all these conditions are sometimes not met. This was the case e.g. during the 2011 Draconids, observable from Europe, where the density of meteor cameras is very high. To get around this difficulty, airplane-based observation of meteors are performed [16, 17, 34]. However, given the complexity of such observations, they are kept for exceptional event, and require the outburst to be known at the very least one year in advance. Another solution consist of putting meteor

observation cameras on-board stabilised stratospheric balloons [37]. Although the optimisation of such flight was recently demonstrated [38], any stratospheric double-station setup still needs to be performed today.

An easier and widely used solution consists of deploying several meteor detection cameras at locations where all the observation conditions are met, considering the weather predictions and the geometry of observation [7]. Such endeavour requires the transportation of all the scientific equipment, the setup and the operation by at least one operator. The overall process might end up taking a lot of time and resources. The MoMET project aims to quickly and easily deploy such double-station meteor observation cameras and fulfill the scientific goals described in Section 1.2.

1.4 Goal of the MoMet project

The observation of meteor showers provides us with scientific information summarised in Table 1. It is clear that a double-station setup allows one to make the most of an observation campaign, by doubling the number of scientific output. The MoMet project aims to cover all the goals listed in Table 1.

The technical goal of the MoMet project is to quickly deploy several meteor observation cameras at a chosen location nearly anywhere on the ground. This way, any forecast meteor shower outburst can be recorded in optimum conditions.

1.5 Specifications

The MoMet setup must comply with the scientific goals as well as some practical issues tied to the observation operations and regulations.

The scientific cameras must comply with meteor observations, namely:

- S.1 at least 1M-pixel resolution to derive accurate trajectories and orbits
- S.2 high sensitivity ($QE > 60\%$)
- S.3 at least video frame rate ($\text{fps} \geq 25 \cdot \text{s}^{-1}$)
- S.4 there must be at least one camera with a wide field of view ($70 < \text{WFOV} < 120^\circ$ - not allsky) in order to catch magnitude 2 meteors and measure a magnitude distribution that will be converted into a size frequency distribution (SFD)
- S.5 there must be at least one narrow field of view camera ($30 < \text{NFOV} < 60^\circ$) in order to measure accurate orbits
- S.6 the acquisition and detection software must be able to record meteors.
- S.7 each station must be geo-located with an accuracy better than a few meters
- S.8 each recorded meteor must be dated at less than one second in absolute time (UT), and better than 0.01 sec for relative time.
- S.9 ideally, the record of meteor spectra should be coupled with the 3D-trajectory and velocity determination, in order to derive the dynamic pressure at which each atomic species is released.

In order to perform double-station observation, the following constraints must be fulfilled:

- D.1 the physical distance between the two stations must lie between 40 and 110 *km* [13, 14]
- D.2 the cameras dedicated to 3D-measurements must survey the same portion of atmosphere, taken between 80 and 110 km of altitude, depending on the velocity of the targeted shower [38]
- D.3 the overall geometry must be such that the meteor trajectory is perpendicular to the two-station baseline. Such constraint usually cannot be met for the entire duration of the shower because of the Earth rotation. In practice, the location of the two stations must maximize the duration when the trajectory is with $\sim 20^\circ$ from the perpendicular to the baseline, especially at the time of the peak of the shower outburst.
- D.4 the cameras dedicated to the trajectory determination must also record the first order of the meteor spectrum recorded with the spectral camera. This allows one to derive the dynamic pressure for the release of each chemical species.

In practice, several practical constraints are added to the scientific ones, namely:

- P.1 the cameras FOV must be clear from obstacle (trees, mountains) and light pollution.
- P.2 the location must be accessible without putting the observer in danger.
- P.3 the ground where the whole setup will be deployed must be flat enough to guarantee the correct orientation of the cameras with respect to each other.
- P.4 since the setup will be transported to remote areas, each package must fit in hand luggage and weight less than 15 *kg*.
- P.5 the packaging must be robust enough for the optics and cameras to be protected from shocks during the transportation.
- P.6 the setup must work on either regular power supply or car battery (or equivalent), so remote and isolated location are possibly used.
- P.7 the cameras must be pointed towards the correct direction, both in azimuth and elevation, to comply with constraint D.3.

2 MoMet hardware

Given all the constraints, the MoMet hardware and software components are summed up in Tables 2 and 3 and fully described below.

2.1 Cameras

The MoMET suitcase use either Basler acA1920-155um or DMK33UX174 cameras, each equipped with the Sony IMX174 sensor, complying with constraints

Table 2 MoMET data acquisition components. The PC server provides network and time services. “Az” refers to relative orientation of the cameras: 0 deg corresponds to the default central pointing direction of the suitcase. Positive value refers to the right hand side of the suitcase. The elevation is set by the user and depends on the 3D geometry of the 2 stations

case #	PC	Camera	Lens	Az (deg)
1	Odroid, server	DMK 33UX174	6mm f/1.4	45
1	Odroid, client	DMK 33UX174	6mm f/1.4	-45
1	Odroid, client	DMK 33UX174	12mm f/1.4	22
1	Odroid, client	DMK 33UX174	12mm f/1.4+grating	0
1	Odroid, client	DMK 33UX174	12mm f/1.4	-22
2	RBpi 4, server	Basler acA1920-155um	6mm f/1.4	45
2	RBpi 4, client	Basler acA1920-155um	6mm f/1.4	-45
2	RBpi 4, client	Basler acA1920-155um	12mm f/1.4	22
2	RBpi 4, client	Basler acA1920-155um	12mm f/1.4+grating	0
2	RBpi 4, client	Basler acA1920-155um	12mm f/1.4	-22

Table 3 MoMET hardware (top) and software (bottom) control components

Name	Purpose
Suitcase	Transportation and deployment
Opto-mechanics	Pointing
Electronics	Power supply
GPS antenna	Time keeping
Total weight	13 kg
Dimensions (case)	558 × 355 × 190 mm
Max camera bandwidth (USB 3)	5 Gbps
RMS + Gstreamer + Aravis	Data acquisition
Web-base GUI	RMS configuration and control
NTP server / client	GPS Time distribution

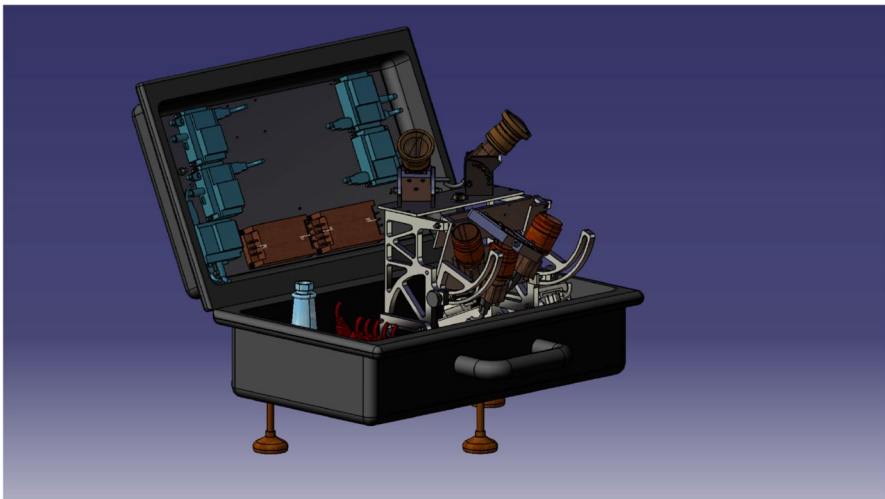
S.1, S.2 and S.3. The optic lenses are 6mm f/1.4 for WFOV (KOWA 10904, S.4) and 12mm f/1.4 for NFOV (BASLER 106879, S.5) applications (Table 4).

2.2 Computers and GPS

Each camera is controlled by a dedicated computer that must pilot the camera, ingest the image flow and detect meteors (S.6). Thanks to the development of the Global Meteor Network, we used RaspBerry-pi 4 (8Go RAM) and the RMS software [40, 42]. We also managed to deploy the RMS software on Odroid XU4Q platforms, also used for stratospheric observations [38, 44]. A server computer is connected to a GPS antenna to comply with constraints S.8 and S.7.

Table 4 MoMET camera characteristics and configuration (source: baslerweb)

Censor name	Sony IMX174
Pixel #	1920 × 1200
pixel size	5.86 × 5.86 μm
sensor size	11.314 × 7.12 mm
optical format	1/1.2
shutter	global
max QE	70% at 550 nm
bits	12
dark noise	6.6 e^-
dark current	3 e^-
saturation capacity	32.7E+03 e^-
max gain	24 dB
frame rate (used by MoMET)	25 s^{-1}
FOV with 12mm lens (NFOV)	FOV: 50.4 × 32.9 deg^2 scale: 1.58 × 1.65 arcmin.pix^{-1}
FOV with 6mm lens (WFOV)	FOV: 86.6 × 61.2 deg^2 scale: 2.71 × 3.06 arcmin.pix^{-1}
Stellar limiting magnitude	5.2

**Fig. 1** Scheme of the MoMet case in observation configuration

2.3 MoMet embedding suitcase: mechanics

The instrument is designed with the help of a numerical twin made with CATIA V5 at the GEPI lab (Paris Observatory, PSL, France), see Fig. 1.

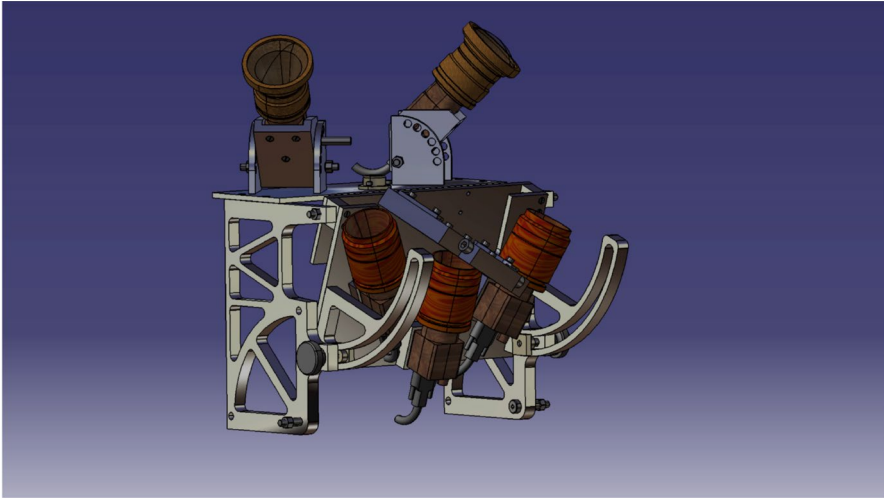


Fig. 2 Capture of WFOV(45°) and NFOV(70°) assembly in the observing position

Since MoMet instrument is meant to be used anywhere in the world and permanently stored in France, it has to travel by plane. Thus, the double-station setup consists of two suitcases that can be deployed independently. Each case contains a set of cameras, lenses and electronic devices required to collect meteor data.

Each case is laid in sub-assemblies as follow :

- WFOV (Wide Field Of View) assembly: Made up of two cameras with wide field of view lenses (KOWA 10904). Scientific requirements set the angle of the cameras to be adjusted from 30° to 45° relative to the horizon. Each camera is mounted on a cradle in independent alt-azimuthal mounts that allow the user to adjust the aiming angle with a pin and a set of holes. The whole assembly contains a plate that support cameras and arms that allow to stretch it once the case is open and fold it before closing the case for transportation. The assembly can be seen with the NFOV camera in Fig. 2.
- NFOV (Near Field Of View) assembly: Made up of three cameras with narrow field of view lenses (BASLER 106879). Scientific requirements D.1 and D.3 set the angle of the cameras to be adjusted from 30° to 70° relative to the horizon. All cameras are mounted on a plate, each one on the side is oriented at 20° relative to the central one that carry out a transmission diffraction grating (EDMUND 49-584) in order to capture the spectral signature of the meteoroids (scientific requirements D.4 and S.9). To adjust the spectrum vertically in the camera sensor a mechanism is designed to tilt the grating according to the optical axis. This mechanism is mounted on a mount that can be set on three angles (28.7° , 0° , -28.7°) relative to the sensor. NFOV and WFOV assemblies are pivot linked so that the orientation of NFOV assembly is adjusted from a knurled knob on each side of WFOV assembly as displayed in Fig. 2.

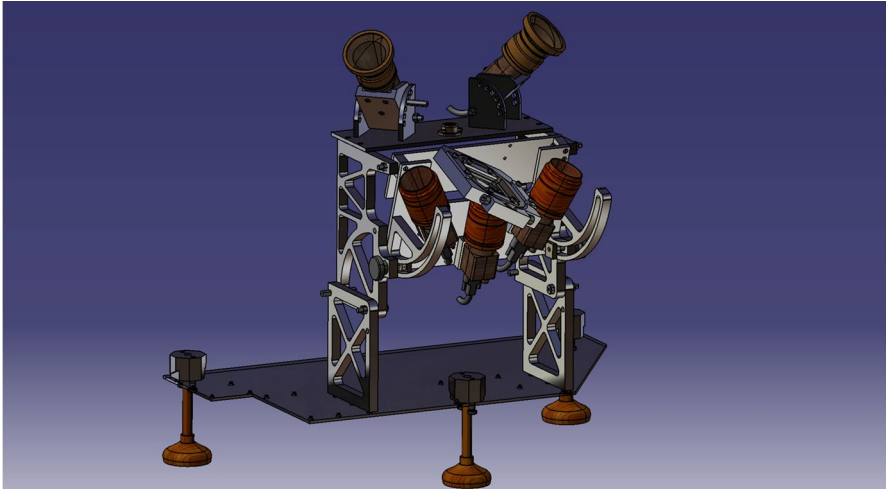


Fig. 3 Scheme of the mechanical assembly that fits inside the MoMet case

- Base assembly: Made of the case, electronics and mechanical supports for the NFOV and WFOV assemblies. The whole mechanical assembly can be seen in Fig. 3.

In order to set the case horizontally, a bubble level is fastened to the WFOV assembly. Three iron feet at the bottom of the case allows the user to level up the case.

2.4 Suitcase: electronics

In order to deploy the MoMet double-station at nearly any flat location, a powering solution was developed to provide electricity to all computers and to the ethernet switch. A power outlet adapter allows to power up the whole system. However, such outlet might not always be available during observation trips in remote and dark areas. For this reason, a battery based power solution was developed. The electronic schematics of the MoMET project is showed in Fig. 4.

The total power consumption of one MoMET suitcase is about 130W. A battery of 150Ah capacity allows the MoMET case to work for 8 hrs.

2.5 Example of a fully built MoMet suitcase

Figure 5 shows a completed MoMET suitcase, during a test campaign at the Observatoire de Haute-Provence (France). The WFOV cameras are already oriented for optimized meteor detection. The elevation of the NFOV cameras still needs to be

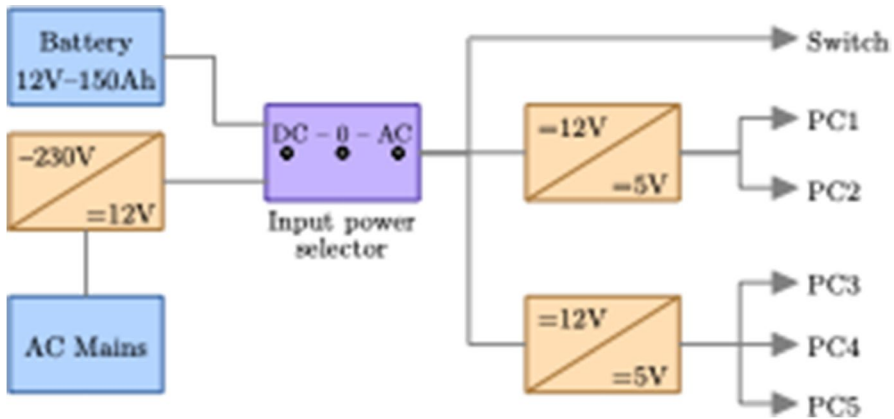


Fig. 4 Schematics of the MoMET power supply electronics (G. Fasola, GEPI, Observatoire de Paris).

tuned in this figure. The 5 RaspBerry-pi 4 mini-computers are visible as green rectangles, in the suitcase lid. The white ethernet cable (lower left, plugged to the switch) allows the user to control all the cameras. The power device is hidden (located at the back of the suitcase basis). The power switch (power plug or battery) is visible under the central NFOV camera.

3 Software

3.1 Single camera solution

Since the hardware must be small and light, the choice of the computer, operating system (OS), data acquisition and meteor detection software are all closely related. Instead of developing a version of a meteor detection software, we chose to use an already existing solution. The “RMS” image acquisition and meteor detection software is intended to run on small RaspBerry-pi mini-computer [42] and perfectly fits the needs of the MoMET project. At the time the MoMET suitcases were designed, we chose the best performing available RaspBerry-pi: model number 4, equipped with 8 Go RAM memory. It runs the RaspBian linux-based operating system.

In addition, we also managed to install the RMS software suite on the Hardkernel Odroid XU4Q mini-computer as well. It runs ubuntu OS, compatible with the RMS software. The Odroid-based solution allows us to use an eMMC memory card, known to have faster read and write capabilities than category 3 SD-card ones (at the time the MoMET project was conceived, in 2020). Tests were performed by installing the OS on the eMMC memory and store the data on the SD card. However, such solution proved not to be stable enough, so eventually, an SD card only solution was adopted and worked perfectly.

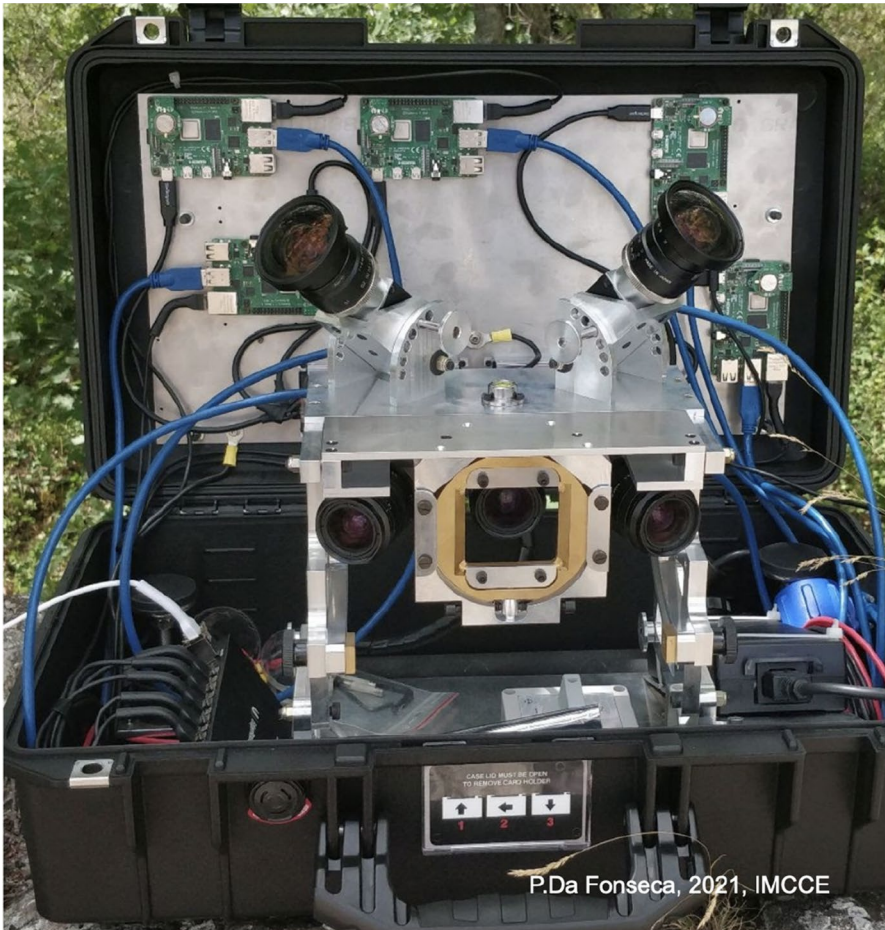


Fig. 5 A fully built and operational MoMET suitcase (P. Da Fonseca, IMCCE)

The **RMS** software offers two different solutions to acquire the images taken by the camera. The first is to use the default v4l2¹ driver. It reads the images created in dev when a new compatible camera is plugged in. The second solution is to use the Gstreamer² library that offers a lot more possibilities. In particular, when coupled with the Aravis³ library it allows the user to employ Genicam⁴ compatible cameras (e.g. of Basler brand). Such a solution opens a wide range of possibility in terms of cameras that can be installed in the MoMET suitcase.

¹ https://www.linuxtv.org/wiki/index.php/V4L2_Userspace_Library

² <https://gstreamer.freedesktop.org/documentation/video>

³ <https://github.com/AravisProject/aravis>

⁴ <https://www.emva.org/standards-technology/genicam/>

The data processing can either be performed by the RMS server, provided each camera has been given a RMS id. Alternatively, the data can be retrieved and processed locally. The trajectory and orbit computation is that developed by different authors [13, 41].

3.2 User control interface

The MoMET user must configure and run the RMS software for each observation campaign. The location must be changed every time the suitcase is moved. In addition, for any partially obstructed field of view, a detection mask must be created and provided to the RMS software to avoid false detections (e.g. moving trees). Similarly, the astrometric plate constants must be determined for each orientation of a given camera. For all these reasons, it seemed to us possible but unreasonable to require the user to connect to each computer and perform such setting operation. Instead, we developed a user interface allowing to set parameters either to one or to all computers at once. We chose to develop a web-based user interface, for its independence regarding the user's computer OS.

For this, the user computer and the 5 MoMET computers are all connected thanks to an ethernet switch. One MoMET computer acts as a server computer and includes a DHCP, NTP and HTTP servers. The web interface allows the user to display, change and propagate the needed parameters to either one or to all MoMET computers at once. A GPS antenna is plugged to the server computer, and a software was written to read the GPS and propagate its thanks to the NTP capabilities. Typical time accuracy of portable USB GPS antenna is 1 *ms*. The NTP server might induce an time difference of up to 10 *ms*, but was not measured for MoMET.

A **scraper** program was written in python to manage all the MoMET computers. It allows the user to perform an image acquisition (thanks to the Aravis library) and display it as a live stream view. In addition, it displays all the RMS configuration and status parameters, with the exception of the GPS data (see below). The RMS log file is also displayed so the user can control the correct RMS operations. The user may change any RMS parameter and the scraper program propagates them to the desired RMS configuration file (either one or all of them). Finally the scraper program manages the RMS software execution.

In order to perform all these functions, several programs were developed and they all run on the server computer. A **monitor** ReactJS program was written that provides the graphic user interface accessible from a web browser. A NodeJS **server** Javascript program was written that scans the network to provide a list of all connected devices, handles broadcast requests, runs clock synchronisation on all devices and sends location data to all devices. A **gps** python script was written that updates the system clock with the time provided by the connected GPS and writes information about the location on a separate file.

The GPS location is read by the server computer and sent to the user interface. A software was written to help the user decide when the GPS location is stable enough (usually 10 – 15 *min* after it is started). The user can then decide to propagate the GPS location to all RMS configuration files at once.

3.3 Software deployment and installation

In order to help cloning the MoMET software, we developed several **install scripts** that provide tools to install all the needed key components and all required dependencies. The key components are: RMS, Monitor, the NodeJS server and Scrapper. A major RMS dependency is the `opencv` library written in python⁵. The installation is performed in a single command line.

In addition, we developed scripts performing all the operations needed during the installation or to tweak the installation. Namely: creating a swap file, extending a partition, reducing the memory needed to run the software on the server computer, updating the software and turning a “client computer” into a “server computer”. Each key component installer automatically runs its own scripts. It solves all the needed dependencies and includes all the files and the commands needed to perform the installation. The installation script automatically determines if the hardware is Raspberry-pi or Odroid.

4 First results and conclusion

4.1 First scientific usage of the MoMET device

The development of the two MoMET suitcases involved the deployment and test in real environment. For this, several test observation campaigns were organized in France during known meteor showers: Geminids 2020 (Observatoire de Haute Provence or OHP), eta-Aquarids (OHP), Perseids (Vendee area).

The first scientific observation campaign involving two MoMET devices happened for the record of the birth of the Arids meteor shower, which had been predicted by several authors [36, 43]. This shower was caused by meteoroids ejected from comet 15P/Finlay. The Earth had never encountered its associated meteoroid stream before. The MoMET suitcases were sent to Southern Chile for the occasion, and a double-station network was set up by an international team of Chilean and French researchers. The shower has been witnessed by both visual observers and meteor cameras, including MoMET devices (CBET 5046). At the time this paper is written (fall 2021), the full analysis is still going on and the full results will be published in a separated and dedicated paper. This campaign was also the occasion to identify a few additional issues (overheating of the computer leading to frame loss, need for on-site astrometric calibration to fasten the scientific outcome etc.) that will improve the MoMET device in the near future.

Figure 6 shows a MoMET device setup, including the user’s own computer, right before a scientific observation. It is worth mentioning that in this case the suitcase was positioned on a table, but could have been placed on the ground. The operator is using his own computer and the web-based interface to tune the different parameters. Figure 7 shows some screen captures of the web-based interface. Figure 8 shows

⁵ <https://pypi.org/project/opencv-python/>



Fig. 6 Operation of a MoMET suitcase (S. Bouquillon, SYRTE/LFCA)

an image of the sky taken with a MoMET NFOV camera during the Arids meteor shower campaign, taken from the Falcon site at Mamalluca observatory (Chile).

Since MoMET is running the RMS software, all the associated tools might be used to process the data, including SkyFit2 (to perform the astrometry reduction) and WMPGpyLib (trajectory solver)⁶ [42]. Compatibility with the trajectory solver developed by [13] is also possible. Figure 9 shows the capture of a meteor by a MoMET device using the RMS software. Figure 10 shows the astrometry calibration for a WFOV MoMET camera. Figure 11 shows a double-station meteor residuals as a function of height above the ground, and Fig. 12 shows the corresponding time lag between the two stations.

4.2 Discussion

The “Mobile Observation of METeors” (MoMET) suitcases allow scientists to quickly set up a double-station meteor dedicated observation network, nearly anywhere on the ground and in a timely manner. Each station runs 5 cameras producing scientific data used to derive physical and dynamical properties of meteoroids in the Solar System. The hardware setup allows the deployment in desert places if needed. The locations must be chosen carefully in order to yield the most scientific results from a given campaign.

The total cost of a MoMET suitcase, for the presented configuration is $\sim 5k\text{€}$, half of which deals with the cameras and lenses ($\sim 0.5k\text{€}$). However, cheaper setup might be built, by e.g. using the camera and lens hardware proposed by GMN⁷. This would reduce the scientific hardware cost by a factor of 10.

⁶ <https://github.com/wmpg/WesternMeteorPyLib>; <https://globalmeteornetwork.org/wiki/>

⁷ <https://globalmeteornetwork.org/wiki/>

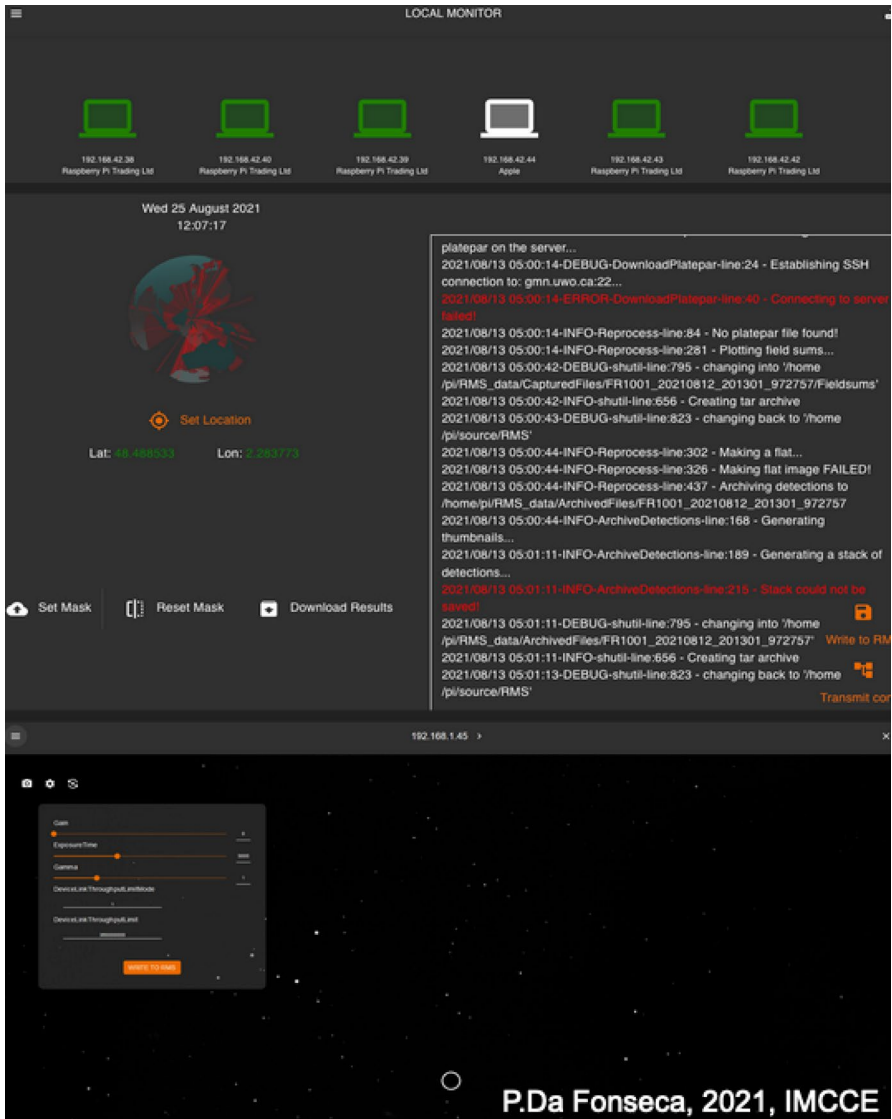


Fig. 7 Several screen captures of the MoMET web user interface. From top to bottom and left to right, it shows respectively: the list of connected computers, the GPS location information, the RMS log, some RMS settings (mask) and live view setting. (P. Da Fonseca, IMCCE)

The limitation of the MoMET device deals with long lasting showers. In such a case, the rotation of the Earth might degrade the orbital geometry allowing an accurate measurement of the meteors trajectory and orbit. In particular, ideally, one would make everything possible so that the radiant never enters the field of view of a given camera. However, considering a WFOV and the constant movement of the radiant for a given observer, such an ideal condition might not be



Fig. 8 Example of image taken with a NFOV ($50.4 \times 33.0 \text{ deg}^2$) MoMET camera (S. Bouquillon - SYRTE/LFCA, P. Da Fonseca - IMCCE)



Fig. 9 A meteor belonging to the Arids shower, captured with a MoMET camera (S. Bouquillon (SYRTE/LFCA), P. Da Fonseca, IMCCE)

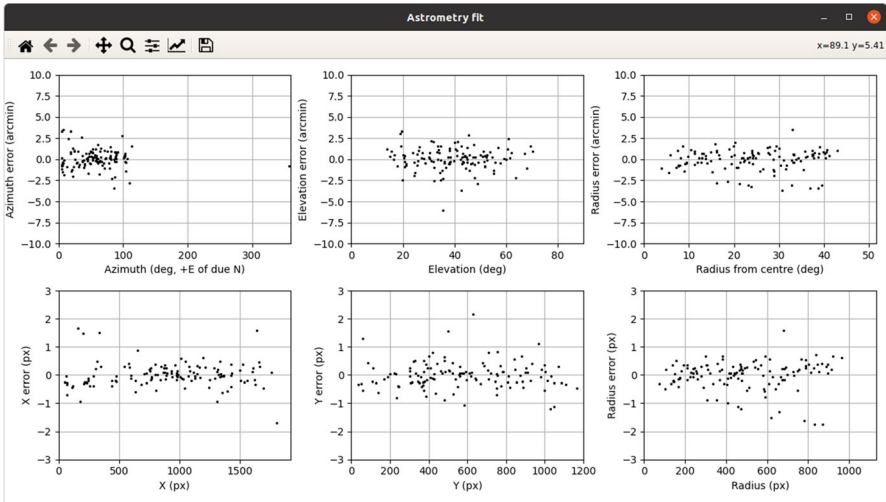


Fig. 10 Astrometry calibration residuals for the WFOV camera, using the SkyFit2 software [42]

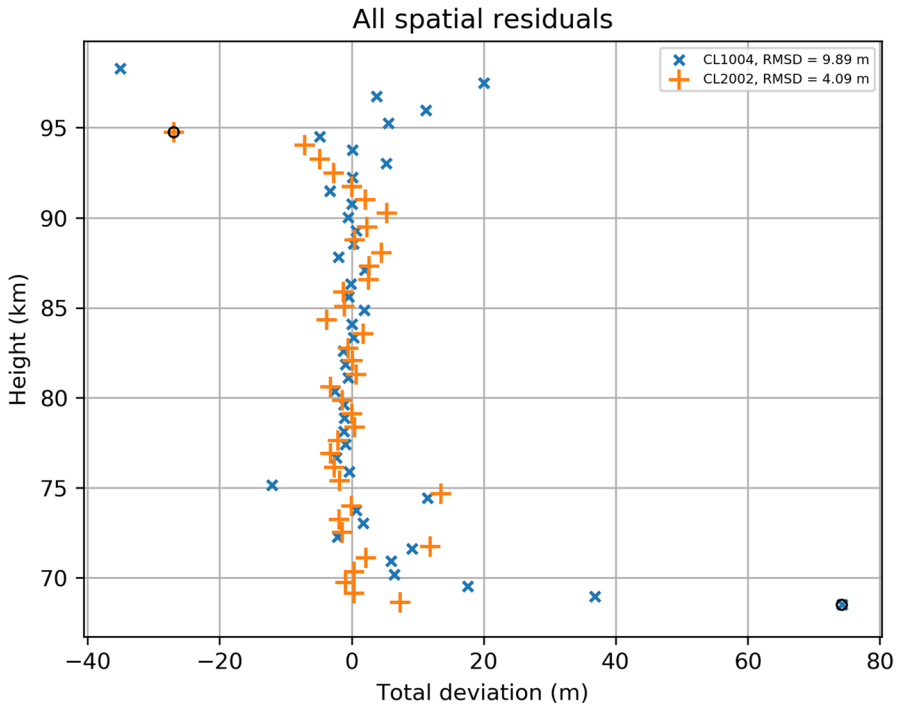


Fig. 11 Residuals of a double-station meteor observed by MoMet (Ack.: Denis Vida, U.W.O). A few aberrant points are visible at the beginning and end of the trajectory

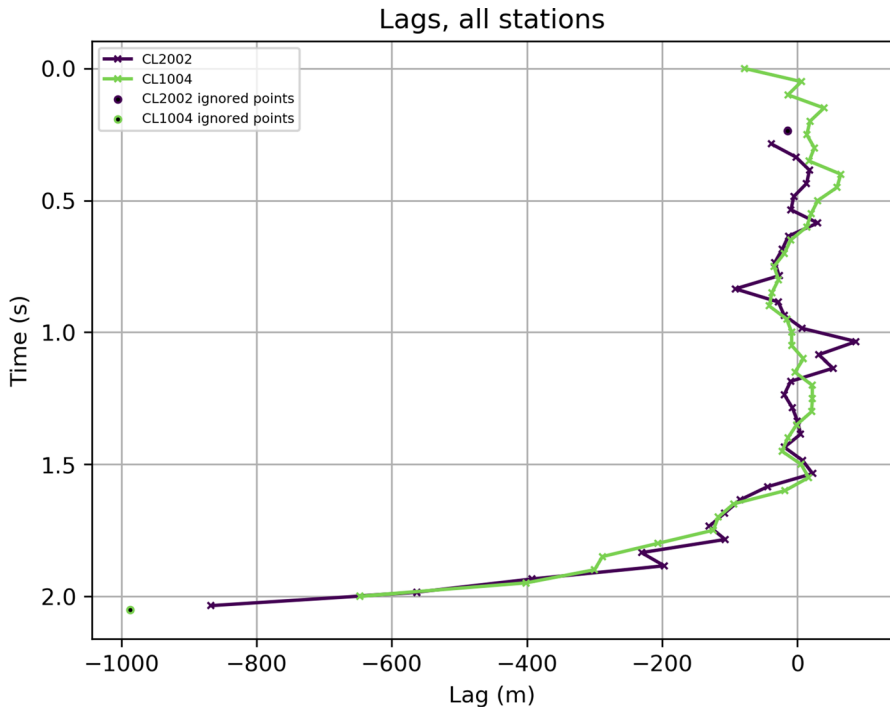


Fig. 12 Meteor lag as computed with the trajectory solver developed by [42]

met for the entire duration of the observation run. For this reason, ideally, a triple-station network (similar to the CABERNET project [3]) involving 3 MoMET devices would be ideal. In addition, the most serious concern for the success of a meteor observation campaign is the influence of the Moon and the presence of clouds at the time of the shower maximum. To overcome such limitations, a stratospheric solution would be ideal [38], since the camera would be located above the cloud, at high altitude where there is nearly no light diffusion.

Acknowledgements The MoMET project is led by astronomers at IMCCE laboratory, Paris Observatory, PSL. It was funded by “Programme National de Planétologie” provided by INSU/CNRS. The Arids observation campaign was made possible thanks to the assistance of the ULISSE/CNRS services, as well as researchers and students from the following institution: LFCA & DAS University of Chile, University de La Serena and El Sauce Observatory. We particularly grateful to Rene Mendez who took care of the observation campaign organisation. The MoMet project uses the RMS software suite for data acquisition, meteor detection and data reduction. We are extremely thankful to Denis Vida (U.W.O.) for the thorough advice and help he provided us to implement and run this software suite. We thank P. Brown (U.W.O.) for refereeing the article and contributing to improve the final version.

Code, data, and materials availability The RMS software is freely available on the Global Meteor Network web pages (<https://globalmeteornetwork.org/wiki/index.php>). The MoMET installation scripts are freely available on gitlab (<https://gitlab.com/Drosaca> : installscripts, mserver, scrapper and monitor packages.).

Declarations

Conflicts of interest There is no conflict of interest.

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