High resolution orbits of Perseids and Geminids with CHIPOlAtA

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This paper focuses on the first results of the high-resolution camera project CHIPOlAtA that aims at measuring velocity with high accuracy, based on a setup with a fast liquid crystal optical chopper. So far three campaigns were carried out during the Perseid and Geminid maxima. The preliminary results, data reduction, a sensitivity analysis and the development of a data reduction pipeline are discussed.

1 Introduction

The precision of meteor orbits in general depends highly on the accuracy of the velocity determination. In optical imaging, this velocity has been measured traditionally with a rotating shutter (Millman, 1936; Kohoutek, 1959)[1]. An alternative method is based on Liquid Crystal (LC) optical choppers (Bettonvil, 2010), which periodically switch between dark state and transparent. These choppers have successfully been applied to All-sky cameras (Bettonvil, 2014a). The current technology enables modulation frequencies up to several hundred cycles/sec (LC-Tec[2]) which opens the way towards very high-resolution observations, allowing for strict D-criteria (Galligan, 2001) in meteor streams. Obtaining orbits with high accuracy is highly interesting as it permits the detection of fine structure in meteoroid streams.

A prototype camera has been build one year ago and tested during the 2014 Perseid shower (Bettonvil, 2014b).

This paper is a status report and focuses on the obtained data so far, the data reduction and further development.

2 Instrument setup

Technical details on the instrumental setup are given in Bettonvil (2014b). Since the first test, done with a single camera, CHIPOlAtA consists of two cameras mounted on the same tripod and aligned such that one long FoV is formed. The cameras used for CHIPOlAtA are Canon 550D 18Mpxl DSLR cameras, equipped with 50mm Nikkor lenses. The choppers of the cameras are mounted in between the camera and the lens and are controlled through one wave generator, enabling precise synchronic operation of both choppers. The tripod mount has a third axis that permits rotation around the aiming point such that the direction of the shower meteors is always aligned with the long axis of the camera field (*Figure 1*). It is planned to motorize the third axis, but the campaigns done so far show that periodic manual alignment is very easy, hence skipped.

All data is stored in jpeg format. Raw is preferred, but not realized yet, due to the still much too large data amount. The exposure control of the cameras is DCF synchronized.

Figure 1 – Setup of the CHIPOlATA system: 2x Canon EOS 550D with Nikkor 50mm F/2 lens, aligned such that they form one long FoV. In between camera and lens the optical choppers are mounted (not visible). In the center a third (All-sky) camera is visible (also with optical chopper), but not being part of CHIPOlAtA.

3 Results

At this moment, three successive campaigns have been done to collect data: during the Perseids in 2014, 2015 as well as during the Geminids 2014. The results of the first campaign were already reported in Bettonvil (2014b). The Geminids 2014 were observed with chopper frequencies of 200 cycles/sec., the Perseids in 2015 (partly) with chopper frequencies of 300Hz, due to the higher velocity of the Perseids. Since the first campaign all observations have been done in multi-station mode for obtaining orbits. For the Geminids 2014, the second station was a Dutch CAMS (Roggemans, 2015) video

[1] apart from video work, which uses the frame rate as reference, but not discussed here.
[2] http://www.lc-tec.com/optical-shutter

station (Jobse, Oostkapelle in the Netherlands), and for the 2015 Perseids, the second station was a DSLR camera set-up at 30-km distance, plus video coverage from two other stations from the *Bosnian Meteor Network* (Mujic, 2015).

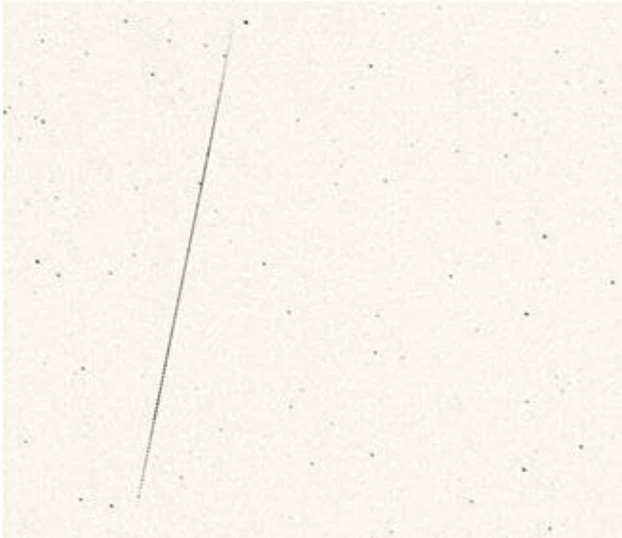

Figure 2 – Example of a Perseid, captured on August 14, 2015: $02^h14^m26^s$ UT, magnitude -1 in Aries, FoV 12x12˚ (crop). Canon 550D + Nikkor 50mm/F2.8, 300 cycl/sec., 100+ breaks, ISO6400, T=14s. Double station.

A camera sensitivity of ISO 6400 (max value for Canon 550D), a diafragma set to F/2.8 to enhance the image quality, and an exposure time of ~15s were used for all the campaigns.

Table 1 lists the total number of meteors captured so far. The total number of trails amounts to 35, of which 23 are double station. The number of meteors is in line with the expected yield (Bettonvil, 2014b), and comparable to 'old-fashioned' 135mm photographic cameras.

Two examples from the last two campaigns are given in *Figures 2 and 3*.

4 Reduction

The Geminids 2014 and the Perseids 2015 were both true double station campaigns, and as such meant for data generation. In this paper I focus only on one of the bright Geminids. All other Geminids as well as the Perseid 2015 meteors, will be a topic for a next paper.

As indicated in the previous section, the Geminids 2014, were observed with CHIPOlAtA plus one of the camera stations of the CAMS Benelux network. The data of the CAMS station has been reduced automatically with the CAMS software package and the created astrometric data

Table 1 – All results obtained so far in three successive campaigns. Shown are location, detector size, optics and resolution, used chopper frequency, and the number of meteors captured, total as well as multi-station.

Shower	Location	Cam (Mpxl)	Lens	Chopper Freqency	Field of view	Resolution	2nd station	#trails	#double station trails
Perseids 2014	Bosnia	12M	50/F2.8	50–200 Hz	18x25°	21"	none	5	none
Geminids 2014	Netherlands	12M + 18M	2x50/F2.8	200 Hz	2x 18x25°	21" + 17"	video	17	13
Perseids 2015	Croatia	18M + 18M	2x50/F2.8	200–300 Hz	2x 18x25°	17" + 17"	12M + video	13	10

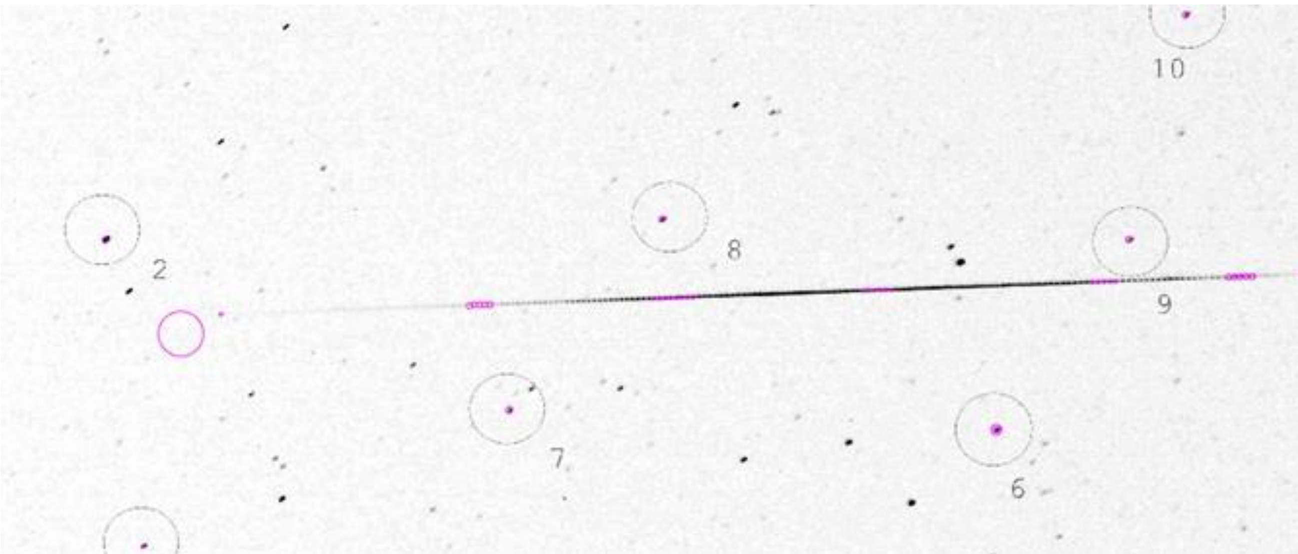

Figure 3 – Example of a Geminid as captured with the camera on December 14, 2015, $00^h22^m44^s$ UT, mangitude -2, in Dra/UMa, crop ~ 14˚x 7˚, Canon 1100D + Nikkor 50mm/F2.8, 200 cycl/sec, ISO6400, T=15s, Twisk, Netherlands. The entire trail contains over 200 breaks. Purple marks indicate measurement points on the meteor trail.

could be read directly into the software package for orbit calculation used for CHIPOlAtA *Meteor35*[3].

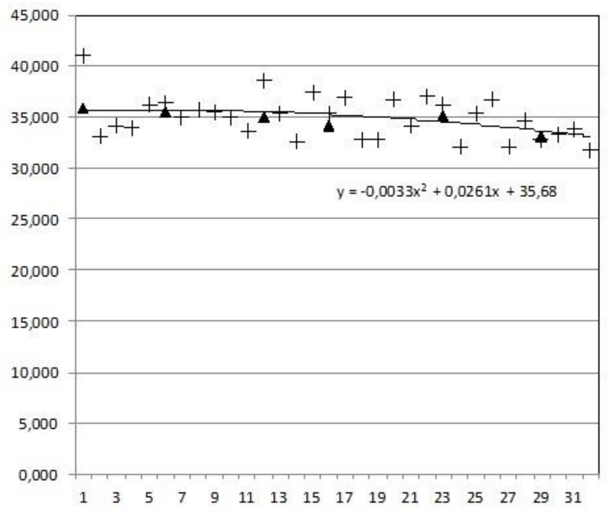

Figure 4 – Velocity profile for the measured data points. Vertical axis velocity in km/s; horizontal axis arbitrary break number. Crosses refer to single data points, solid triangles to a 6-pt average. The solid line represents a polynominal fit. There is evidence for deceleration.

The CHIPOlAtA data was reduced manually. The analyzed Geminid was of magnitude -2 and contains >200 breaks (*Figure 3*). First a set of reference stars was selected and marked in the picture (*Figure 3*), reference star coordinates looked up in Stellarium[4], and then their centroids measured in SAOImage DS9[5]. The astrometry has been done in *Meteor35*. Astrometry of these long focal length lenses is easy and accuracies of 6” (0.25 pxl) are easily reached.

For a first indication, five clusters of meteor breaks were measured, and thereafter the trajectory and velocity computed with *Meteor35*. The aim was to verify whether an indication for deceleration could be found. *Figure 4* shows the velocity along the trail. There is indeed an indication for a decrease in velocity. A more accurate measurement of the entire trail remains to be done.

5 Sensitivity analysis

CHIPOlAtA is able to measure the velocity with an increased accuracy. In order to verify if the velocity in this case is still the largest contributor to the global error in the orbit calculation, a sensitivity analysis was done on the most relevant input parameters.

As a measure of the accuracy of the orbit the D-criterion is used, which expresses in a value how well two meteor orbits do belong to each other (Galligan, 2001). The smaller the D-criterion the better two orbits fit. By varying one-by-one the different input parameters (i.e. accuracy of the astrometry, the timing of the meteor, the geographical longitude and latitude) in the reduction process and by computing the D-criterion value, insight can be obtained in the sensitivity of the various parameters.

Table 2 – Sensitivity analysis for different input parameters. The estimated error in each input parameter (column 2) is used for computation of D_{SH}. Despite the higher accuracy of CHIPOlAtA clearly the velocity remains the dominant error source.

Parameter	Accuracy	D_{SH} PER	D_{SH} GEM
Velocity (km/s)	0.040 0.036	0.0018	0.0019
Time (sec)	30 30	0.0001	0.0002
Astrometry RA (°)	0.002		0.0003
Astrometry Decl. (°)	0.003		0.0002
Longitude station (°)	0.17		0.0001
Latitude station (°)	0.17		0.0001

Table 2 lists the results for both the Perseids and the Geminids. The from the data reduction estimated velocity error (~0.04 km/s) translates into a D-criterion of ~0.0020. All other input parameters give D-criterion values that are considerably smaller. We learn from this analysis that the velocity still is the most sensitive parameter in the orbit calculation.

6 Pipeline development

As described above, the analyzing of data has been done mostly manually so far. In order to reduce a larger number of trails, a more automated reduction pipeline is desired. *Figure 5* illustrates the layout for such pipeline:

- A recognition tool will be designed to identify meteor trails in the stack of images.
- The measurement of the images will be done with *SAOimage DS9*[5] as is done already. This astronomical image-processing tool facilitates centroiding and export of the measurement data. First, a set of 6 bright stars is measured and labeled with their names. Then a larger set of more reference stars is measured, but without identification. Finally, the meteor data is measured. All measurement data is automatically copied into a .txt output file.
- Reference star catalogue data (RA, decl, brightness) is obtained from a catalogue (e.g. Bright Star Catalogue[6]).
- Both the *SAOimage DS9* text output file and the catalogue data are imported into *Meteor35*.
- *Meteor35* then performs astrometry on the preselected 6 stars. Based on this astrometric solution the celestial coordinates of all other reference stars are computed and candidate reference stars matched

[3] Software package for reduction of meteor orbits, including astrometry, atmospheric trajectory calculation, orbital elements, and developed by the KNVWS Meteor Section.
[4] http://www.stellarium.org
[5] http://ds9.si.edu/site/Home.html
[6] http://tdc-www.harvard.edu/software/catalogs/bsc5.html

from the star catalogue. Then, with the complete set of reference stars the astrometric calculation is repeated, which gives the final astrometric solution.

- Based on the astrometric solution the celestial coordinates of all points on the meteor trail are computed.
- *Meteor35* then computes the atmospheric trajectory (ground track, altitude, radiant, velocity) from the observations of different stations (2 or more), for each point on the meteor trail.
- Computation of the deceleration and the pre-atmospheric velocity V_∞, is done in various ways: *Meteor35* is planned to do an automatic fit on the velocity data and to obtain the highest accuracy two more manual methods are also foreseen: fitting the data entirely manually (being flexible in fitting, data rejection, etc.); and FFT analysis (of parts) of the trail (Bettonvil, 2008, 2014b).
- After having determined V_∞ as well as the deceleration, both the heliocentric orbit as well as the dark flight trajectory (in the case of meteorite dropping fireballs) is computed in *Meteor35*.

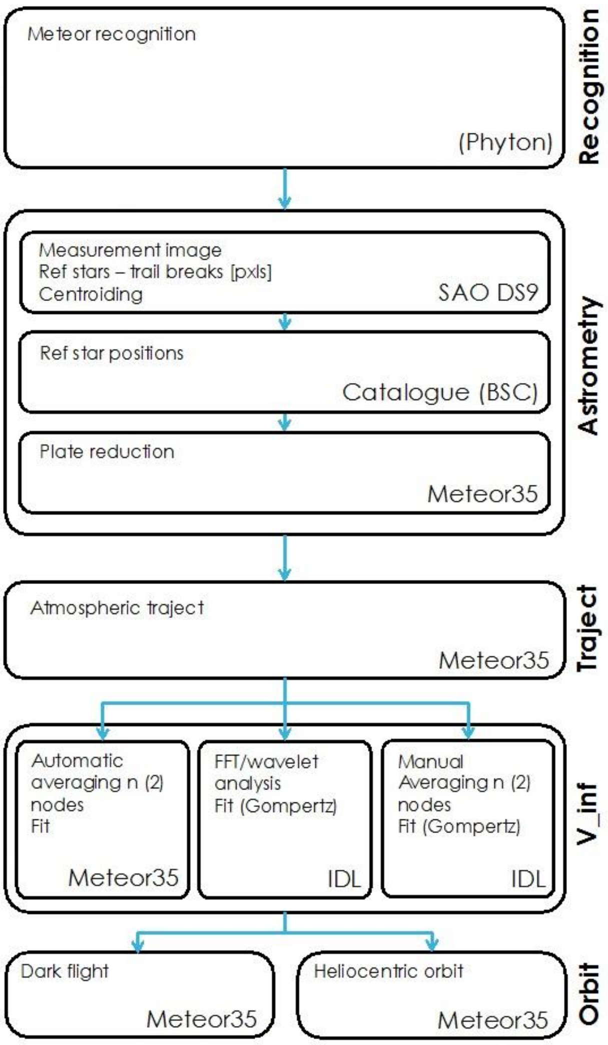

Figure 5 – Schematic pipeline for the data reduction.

The pipeline can be applied as well to the narrow-field CHIPOlAtA data as to the wide-angle or All sky data (Bettonvil, 2015): the astrometric engine of Meteor35 can reduce a wide variety of lenses, as long as the lens projection is (approximately) known.

This implicates that the pipeline is still not entirely automatic. In particular, the astrometry requires still some manual intervention, as well as the computation of V_∞. Since both are critical steps this has been done on purpose. In a next step further automation could be achieved, but this is not discussed in more detail in this paper.

7 Conclusions

The three campaigns done with CHIPOlAtA so far were all three successful. The amount of data per campaign is comparable to analogue photographic work (Betlem, 1999): ~5 trails per night per camera. Despite the much higher precision, this is far less in quantity than ‘modern’ video work. Upscaling to all sky (12–20 cameras per station) is a way forward, similarly as done in the era of the analogue photography. The CHIPOlAtA project will focus on the major showers PER, GEM and QUA for at least the next coming few years. Possibly the project will be up-scaled in some way as there is broader interest in small dedicated networks in the Netherlands, as well as abroad (PSC, Serbia).

The Perseids 2015 showed that speeding up the chopper to 300Hz cycles/sec. works satisfactory. In theory the plate scale could therefore be increased even more, but would require very fast lenses to keep the sensitivity at the same level.

Next steps in the project are the development of a (semi-) automatic reduction pipeline and thereafter reduction of the remaining data.

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The author, *Felix Bettonvil*, during his lecture (Photo by *Axel Haas*).