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Automated systems for the analysis of meteor spectra: The SMART Project

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ABSTRACT

This work analyzes a meteor spectroscopy survey called SMART (Spectroscopy of Meteoroids in the Atmosphere by means of Robotic Technologies), which is being conducted since 2006. In total, 55 spectrographs have been deployed at 10 different locations in Spain with the aim to obtain information about the chemical nature of meteoroids ablating in the atmosphere. The main improvements in the hardware and the software developed in the framework of this project are described, and some results obtained by these automatic devices are also discussed.

1. Introduction

Emission spectroscopy plays a fundamental role in meteor science, since this technique provides information about the chemical nature of meteoroids ablating in the atmosphere and their parent bodies (Borovicka, 1993, 1994; Trigo-Rodríguez et al., 2003, 2009; Madiedo et al., 2013a, 2013b). With this aim, a systematic meteor spectroscopy survey has been conducted in Spain since 2006. This survey, which is called SMART (Spectroscopy of Meteoroids in the Atmosphere by means of Robotic Technologies) employs an array of automated spectrographs deployed at 10 meteor-observing stations in this country (Table 1).

Favourable weather conditions in Spain play a key role in the successful development of the SMART project. Thus, as a result of this survey several hundreds of meteor spectra have been recorded so far. These include emission spectra produced by sporadic fireballs, but also by events associated to major and minor meteoroid streams (Trigo-Rodríguez et al., 2009; Madiedo et al., 2013a, 2013b, 2013c, 2013d, 2013e, 2013f, 2013g, 2014a, 2014b, 2014c, 2014d; Madiedo, 2014; Madiedo, 2015a; Madiedo et al., 2016). In addition, several afterglow spectra have been also obtained (Madiedo et al., 2014e; Madiedo, 2015b). The project currently focus mainly on meteor events associated with minor streams, since their spectra can provide new clues to improve our knowledge about these swarms. In this paper I provide a description of these systems, and some results are also presented.

2. Instrumentation and methods

2.1. CCD videospectrographs

These spectrographs are slitless devices based on the same low-lux monochrome CCD video cameras employed at the meteor stations listed in Table 1 to monitor meteor and fireball activity (Madiedo and Trigo-Rodríguez 2008). Thus, Watec 902H2 Ultimate cameras (manufactured by Watec Corporation, Japan) are employed. These can image meteor spectra for meteor events with a luminosity higher than mag. -3. Meteor detection is performed by means of the UFOCapture application and also by means of a software developed by the author. Because of their high sensitivity, these systems operate during the night, although they can also work under twilight conditions. Fast optics are employed (f1.0 to f1.2) and the devices cover an area in the sky ranging from $90\times72^\circ$ to $14\times11^\circ$. Their typical spectral resolution is of around 1.3 nm/pixel. The video spectrographs are based on 8-bits (i.e., 256 grey levels) devices.

A holographic diffraction grating (with 500 or 1000 grooves per mm, depending on the imaging device) is attached to the optics of each CCD video camera. These devices generate interlaced analogue video imagery in AVI format according to the PAL video standard. Thus, the images are recorded with a resolution of 720×576 pixels at a rate of 25 frames per second (fps). Since these images are deinterlaced later on for data processing, these videospectrographs provide a time resolution of around 0.02 s. This makes possible, for instance, the analysis of the evolution with time of meteor spectra. Each video spectrograph is connected to a PC computer by means of a video acquisition card. For desktop computers, external USB acquisition cards (models EasyCap

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Table 1
Location of the meteor observing stations involved in the SMART Project, and devices employed (V: CCD video spectrographs, S: slow-scan CCD spectrographs).

Station #	Station name	Longitude (W)	Latitude (N)	Alt. (m)	Devices
1	Sevilla	5° 58' 50"	37° 20' 46"	28	V+S
2	Cerro Negro	6° 19' 35"	37° 40' 19"	470	V+S
3	El Arenosillo	6° 43' 58"	37° 06' 16"	40	V
4	Huelva	6° 56' 11"	37° 15' 10"	25	V+S
5	Observatorio de Sierra Nevada	3° 23' 05"	37° 03' 51"	2896	V
6	Observatorio de La Hita	3° 11' 00"	39° 34' 06"	674	V
7	Cerro Negro (CN2)	6° 19' 28"	37° 39' 38"	375	V
8	La Pedriza (OAA)	3° 57' 12"	37° 24' 53"	1030	V
9	Calar Alto (CAHA)	2° 32' 46"	37° 13' 25"	2168	V
10	Observatorio de La Sagra	2° 33' 57"	37° 58' 58"	1520	V+S

DC60, manufactured by EasyCap Co., China, and KW-2800D, manufactured by Kworld Computer Co., Taiwan) and also internal PCI acquisition cards (model KW-TV878RF, manufactured by Kworld Computer Co., Taiwan) are employed. However, for notebook computers just the external USB cards can be employed. These notebooks are used at the mobile station at Cerro Negro and also at the station operating at La Hita Astronomical Observatory. These video acquisition cards digitize the imagery produced by the CCD cameras, and these images are then stored on a hard disk. No video compression is employed in order to preserve image quality. The computers are synchronized by means of GPS antennas (model 25-HVS, manufactured by Garmin), which allow for a regular correction of the computer's internal clock. In this way it is possible to keep a precise timing of meteor and fireball events, but also a proper synchronisation among the different observing stations.

Despite the grating placed in front of the lens blocks some of the incoming light, these video spectrographs are sensitive enough to image mag. +3/+4 and brighter stars. And these stars can be employed to calibrate the images, so that an astrometric analysis can be performed. Thus, atmospheric trajectories can also be calculated for multi-station events by following the planes intersection method (Ceplecha, 1987) and so the evolution of the conditions in meteor plasmas as a function of height (and not just as a function of time), can be analyzed.

2.2. Slow-scan CCD spectrographs

These spectrographs consist of five slitless slow-scan high-sensitivity CCD devices that employ 1000 lines/mm diffraction gratings and fast optics (f1.0 to f2.8). Their typical spectral resolution is of about 0.5 nm/pixel. Two of these are manufactured by ATIK (models ATIK 4000LE and ATIK 16HR), and the other three are manufactured by SBIG (one ST10 and two ST8 CCD cameras). These operate since August 2011 from stations #1, #2 and #10 in Table 1 (Sevilla, Cerro Negro, and La Sagra, respectively). These spectrographs generate imagery which is stored in FITS files on GPS synchronized computers. The exposure time is adjusted according to the conditions of the night sky during the observing session. Typically 30 s exposures are employed, but shorter times must be used when the Moon interferes with the observation, especially when the transparency of the sky is not optimal. When the device takes an image it stops imaging till these data are transferred to the computer. The resulting dead time between two consecutive images, which is of about 10 s, is one disadvantage with respect to the operation of CCD video spectrographs, which can work continuously from dusk to dawn. Another disadvantage is that they cannot operate under twilight conditions.

Each system covers an area in the night sky ranging from 32 × 32° to 50 × 50°. Three of them are pointing to fixed horizontal coordinates. However, two of the spectrographs are placed on robotic altazimuth mounts, so that they can be aimed to any point in the sky. These mounts have been also developed in the framework of SMART.

Since no rotary shutter or any similar device is employed, the images taken by these slow-scan CCD spectrographs cannot provide meteor velocity data. So, the recordings obtained with these devices cannot be employed to obtain the orbit in the Solar System of the meteoroids producing the emission spectra. Nevertheless, their imagery can be combined with the recordings obtained by the CCD video cameras to calculate these orbital parameters.

2.3. Locations

The geographical coordinates of the meteor observing stations involved in the SMART Project are listed in Table 1. These perform a systematic monitoring of meteor activity during the night by means of low-lux CCD video cameras (Madiedo and Trigo-Rodríguez 2008), but also employ spectrographs to record meteor spectra.

Although the meteor observing station at Sevilla (Southwest of Spain) is in operation since 2005, its first spectral systems were setup in August 2006. Presently this station employs 4 videospectrographs and 1 slow-scan CCD spectrograph. In August 2006, a new mobile meteor monitoring system based on low-lux CCD video cameras and videospectrographs was designed. Since then, this station is being regularly setup when necessary at Cerro Negro (station #2 in Table 1), a dark countryside environment located at about 60 km north from Sevilla. This location provides darker night skies than Sevilla. Power consumption is a major drawback for the operation of this station, and this issue is solved by using low consumption computers (laptops) fed by an array of 8–10 12-volts car batteries with a capacity of 74 Ah. In this way, this mobile station can operate continuously from dusk until the following sunrise. Currently, 11 videospectrographs and 2 slow-scan spectrographs operate at this location. These devices are not placed in any enclosure or housing and so the gratings are exposed. Since this implies that they can degrade because of dust, these gratings are regularly inspected and replaced with new ones when necessary. The main purpose of this mobile station was to provide a double-station system with Sevilla, but also with El Arenosillo, the third station setup in the framework of SMART in September 2006. This is located in a dark place at about 70 km west from Sevilla and currently operates 5 videospectrographs placed inside non-heated camera housings. The same configuration is employed at Huelva (station # 4 in Table 1), another station in a suburban location at around 25 km from El Arenosillo and where 4 videospectrographs and 1 slow-scan CCD spectrograph are in operation since May 2007.

Once locations #1 to 4 in Table 1 provided an optimal multi-station system in the Southwest of Spain, additional locations were studied in order to expand the coverage of the SMART project to the Southeast and the center of this country. Thus, in November 2009 a new meteor observing station was setup at the Sierra Nevada Astronomical Observatory (OSN), in the Southeast of Spain. One year later, in November 2010, the SMART system was expanded to Central Spain with the deployment of a new station at La Hita Astronomical Observatory. Presently, 7 CCD videospectrographs operate at this station. The coverage in the Southwest area of the country was reinforced with the deployment in October 2013 of the meteor station at La Pedriza and in July 2014 with the station at the Calar Alto (CAHA) Astronomical Observatory. These operate 4 and 5 videospectrographs, respectively. The last station was setup in March 2015 at La Sagra Astronomical Observatory, with 5 CCD videospectrographs and one slow-scan CCD spectrograph.

2.4. Positional control

One of the main issues that affect the recording of meteor spectra is