Spectrum calibration with orthographic projection

Summary

In http://www.meteorastronomie.ch/images/Meteor_Spectroscopy_WGN43-4_2015.pdf a method is described to linearize meteor spectra for easy analysis by a transformation of the images to an orthographic projection.
The method is demonstrated here with a color spectrum

Equipment

The following spectrum was recorded by Koji Maeda (thank you for permission to reproduce this spectrum here) in Japan with

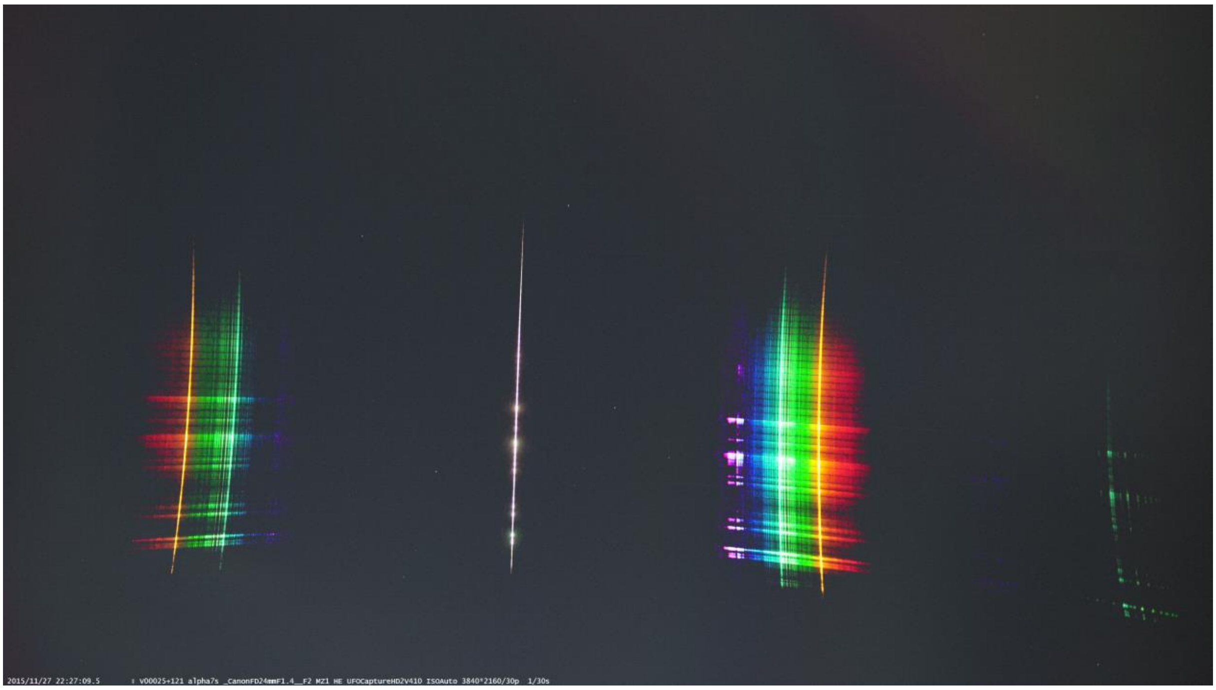
- UFOCaptureHD2
- SONY alpha 7s + 24mm/F1.4 lens + 600 lines/mm grating, 24p

Original image

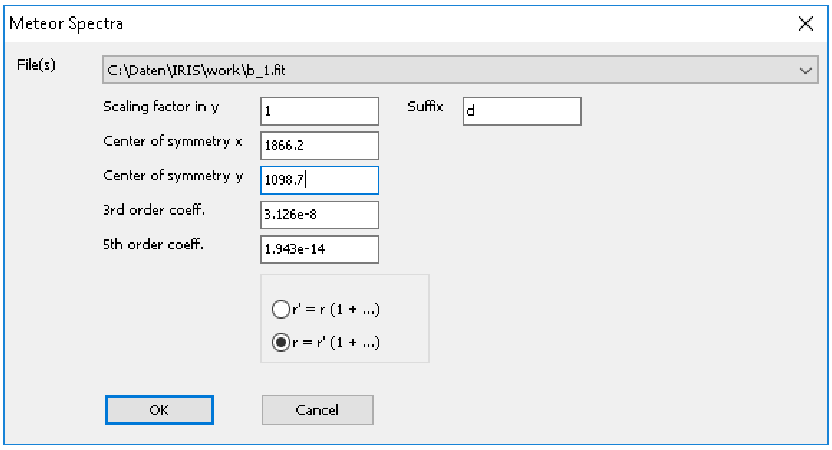
From the video this beautiful peak image was extracted. The zero order image of the meteor passes close to the center of image, first orders are left and right of the zero order image. Some lines of the second order are visible at far right. The spectrum shows the typical features of a meteor spectrum

- Hyperbolic shape of spectrum towards the bottom of the image area
- Nonlinear dispersion far from the center of the image (the distance of the Na line from the zero order varies along the meteor path

M20151127_222709_JPMZ1_HEP.bmp

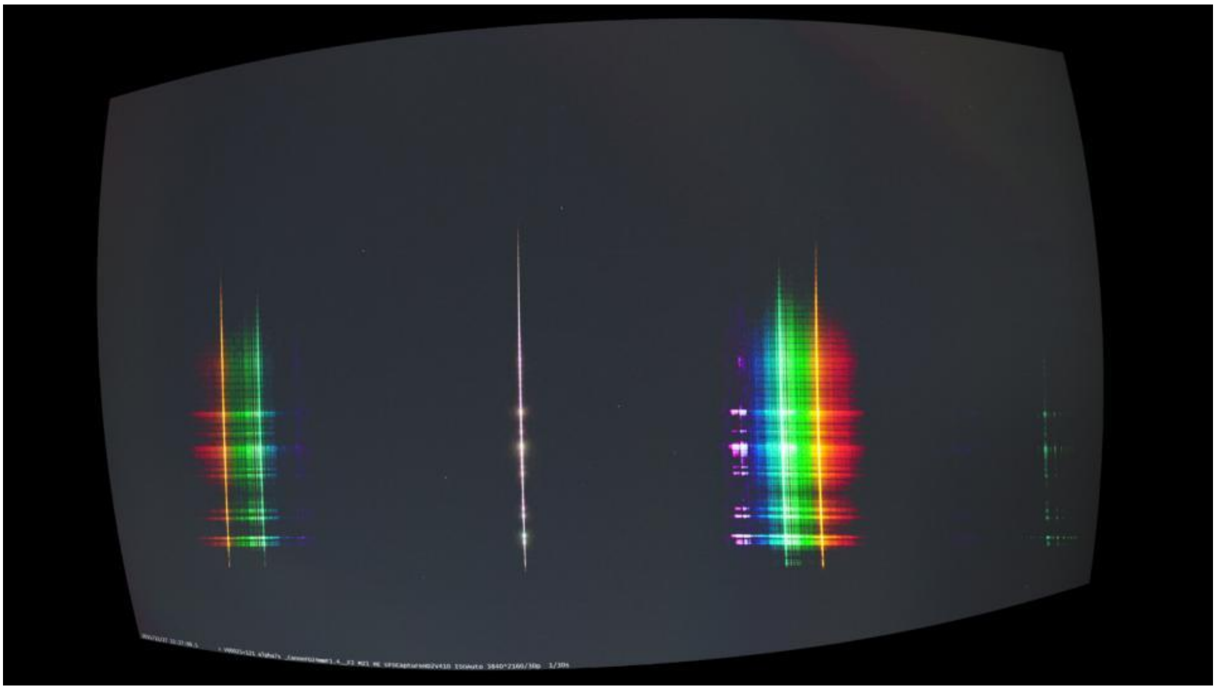


This image was transformed to an orthographic projection with the following transformation equation:
r = r'*(1 + a3*r'^3 + a5*r'^5)



r and r' are measured from the image center. The transformation coefficients a3 and a5 have been determined with a least square fit from calibration spectra with a green laser (details see at the end).
The transformation is similar to the correction of lens distorsion, typical for wide angle lenses.
After the transformation to the orthographic projection

- the spectra of the individual frames are linear
- the dispersion is constant everywhere in the image area (notice the Na lines of the first order spectrum are parallel to the zero order)
- the image was rotated so all spectra are parallel to the horizontal for easy extraction of the individual spectra



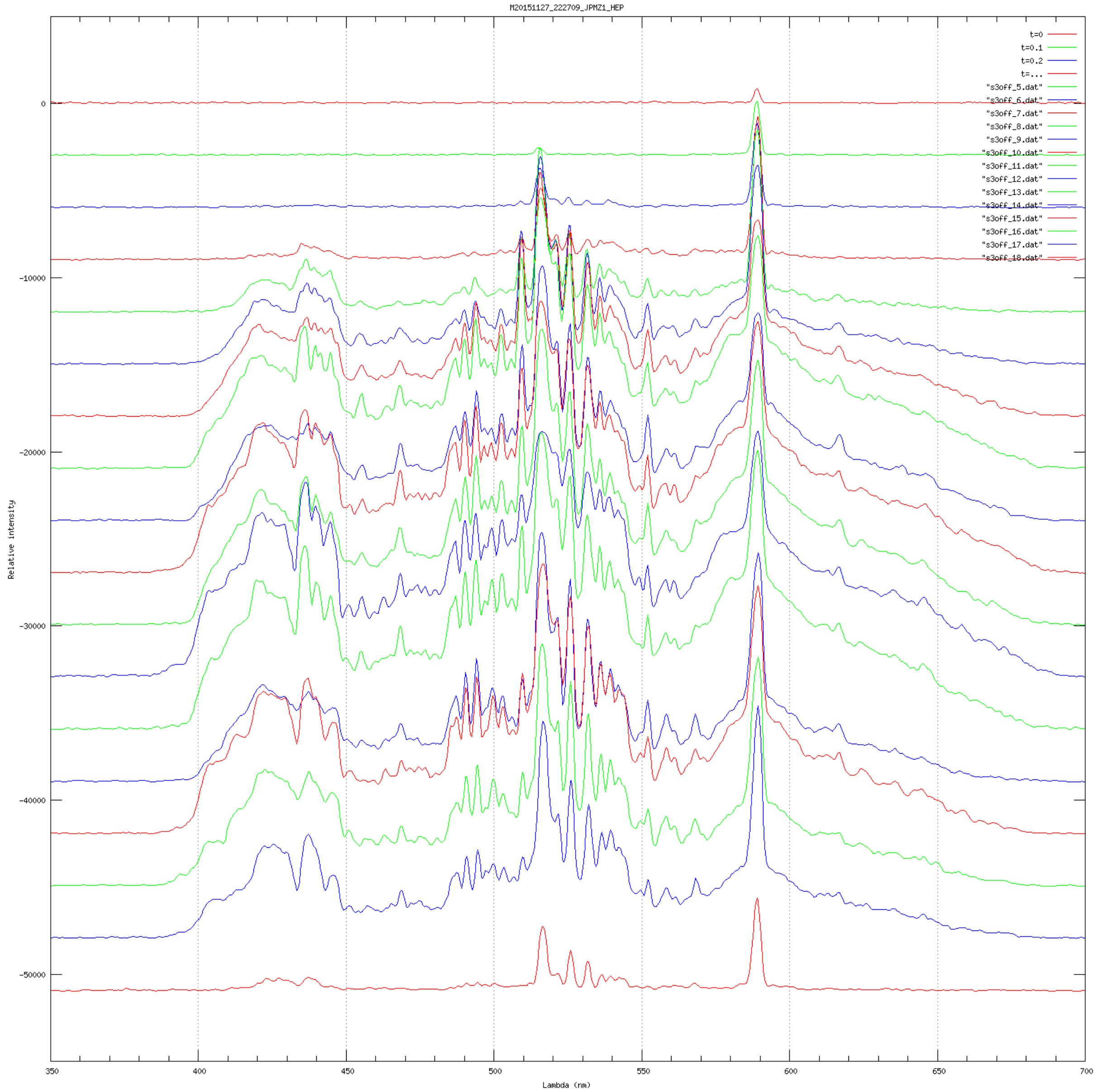
Analysis of video file

The peak image above was used mainly to give an overview of the method. For the detailed analysis of the meteor spectra the video file was used. The following steps were performed

- extraction of individual frames from video (with VirtualDub)
- converting to black and white images (the spectral information is in the image position)
- determination of background signal (average of first 20 frames without meteor)
- subtraction of background from meteor spectra
- transformation of spectra to orthographic projection, using the same parameters as for the color image

- rotation of spectra
- adding lines of image containing spectrum
- converting to uncalibrated raw 1-dimensional spectrum
- calibrating spectra using position of zero order and known dispersion

Most of the processing was done in IRIS.
For the following graphic the 54 individual spectra have been added in 18 groups of three spectra in order to improve S/N. The intensities are somewhat arbitrary, large intensities were rescaled to fit the graph (time interval between spectra 0.1 sec, top to bottom), saturation of spectra is visible.



Details of calibration procedure

A green laser reflection was pointed at the camera at different vertical positions, producing monochromatic spectra from -2nd order, - 1st order, zero order to 1st order. The spectra simulate meteor spectra at different positions of the image and are curved and show nonlinear dispersion (larger separation of orders in the corners)

Calculation of transformation parameters:

The x,y-coordinates of the different laser spots were measured and assigned to the different orders of the spectra

From a least square fit of the measured positions with lens – grating model the desired transformation parameters were obtained.

As input in the model the following fixed parameters were used:

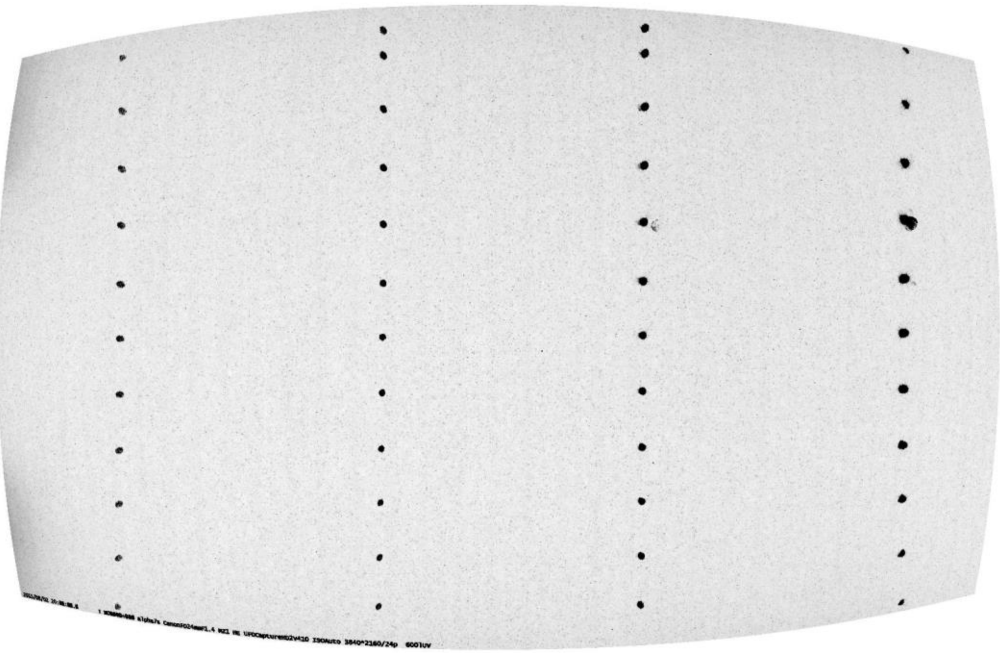
- Lambda: laser wavelength,
- G: grating lines/mm,
- Px: pixel size,
- Nx, Ny: image size

Fit parameters:

For the least square fit the following parameters were adjusted:

- Disp0: dispersion at lens center → gives dispersion of transformed image
- a3, a5: lens transformation coefficients (r = r'*(1 + a3*r'^3 + a5*r'^5)
- Alpha: Grating rotation angle, can be used to align transformed spectra parallel x-axis
- dx, dy: offset optical axis from image center in original image
- (yx): py/px, pixel ratio (can be fitted if not known, for Sony alpha square pixels → yx=1.00
- x1, y1, … xn, yn: position of zero order of different spectra

The resulting parameters were inserted in the transfomation equation. With the following result of the transformation:



The spectra are linear, scale is everywhere the same, 0.624 nm/pixel, the laser wavelength of 518 nm was confirmed by comparison with the Na-line of a meteor spectrum.