

Analysis of Digital Meteor Spectra

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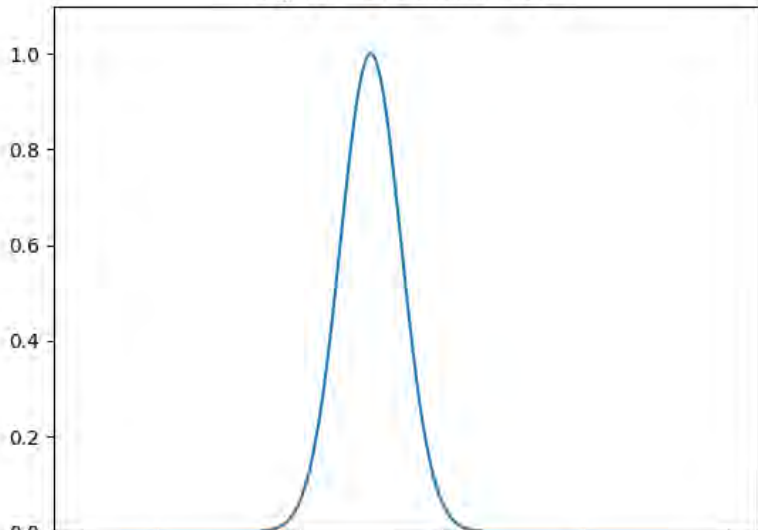
- Introduction to meteor spectra
- Equipment
- Obtaining the spectrum from the image
- Analysing the spectrum
- Current progress

Introduction to meteor spectra - Temperature components

- The observed spectrum is a superposition two spectra
- Main spectrum (head) - **4000 - 5000 K**
 - Fe I, Mg I, Ca I, Ca II, Al I, Ti I, Mn I, Cr I, Na I
- Second spectrum (shock-wave) - **~ 10000 K**
 - Fe II, Ca II, Mg II, Ti II, Si II
- Second spectrum present only in fast meteors
- Observed line profiles are instrumental
 - Synthetic spectrum \longrightarrow Voigt function

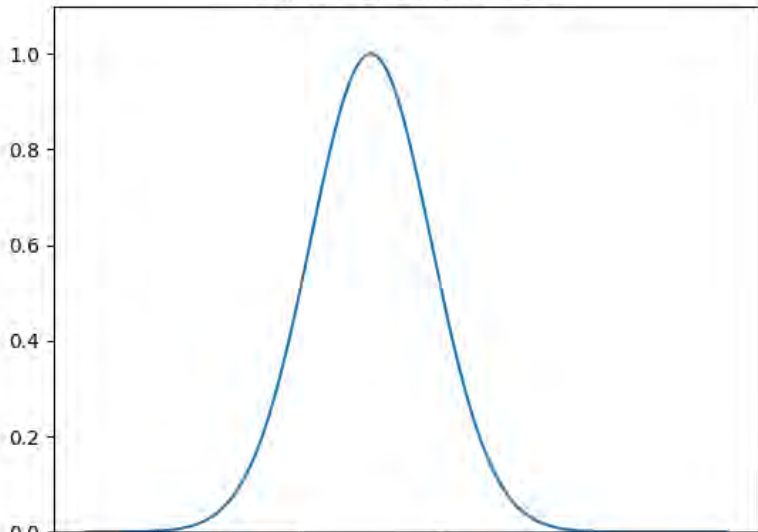
Voigt profile: Gaussian factor

Sigma = 1, Gamma = 0.5



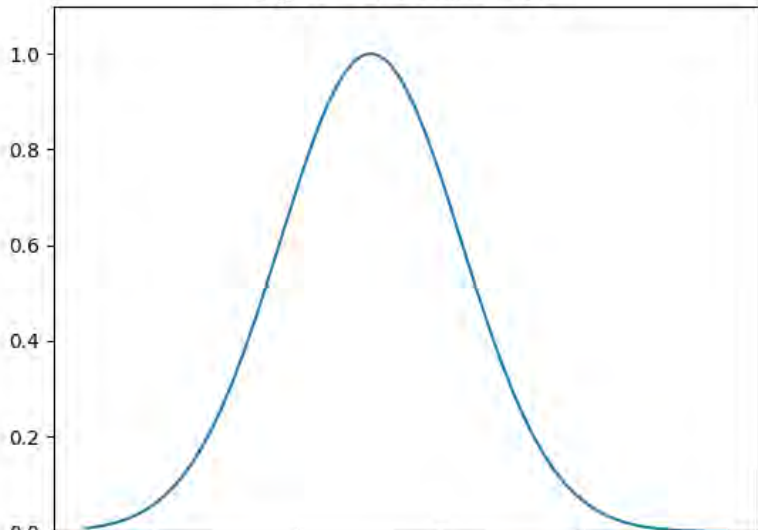
Voigt profile: Gaussian factor

Sigma = 2, Gamma = 0.5



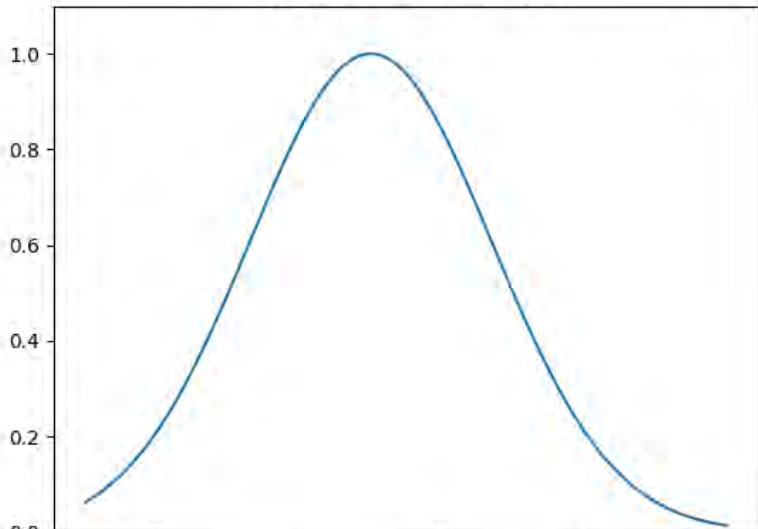
Voigt profile: Gaussian factor

Sigma = 3, Gamma = 0.5



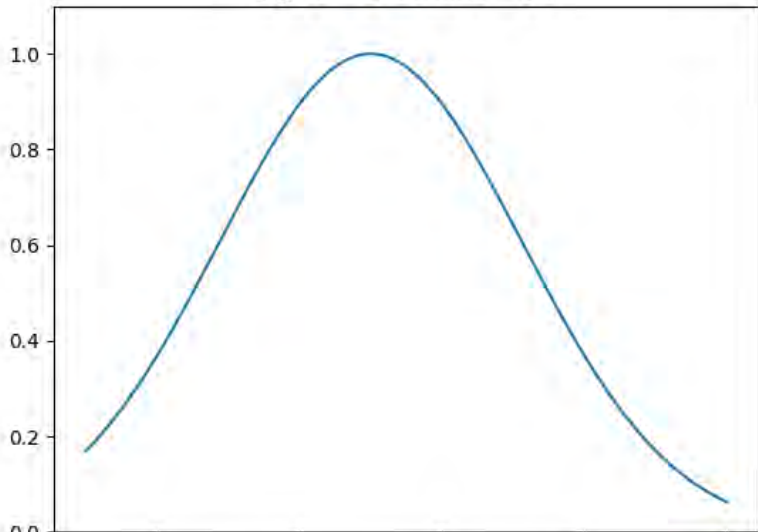
Voigt profile: Gaussian factor

Sigma = 4, Gamma = 0.5



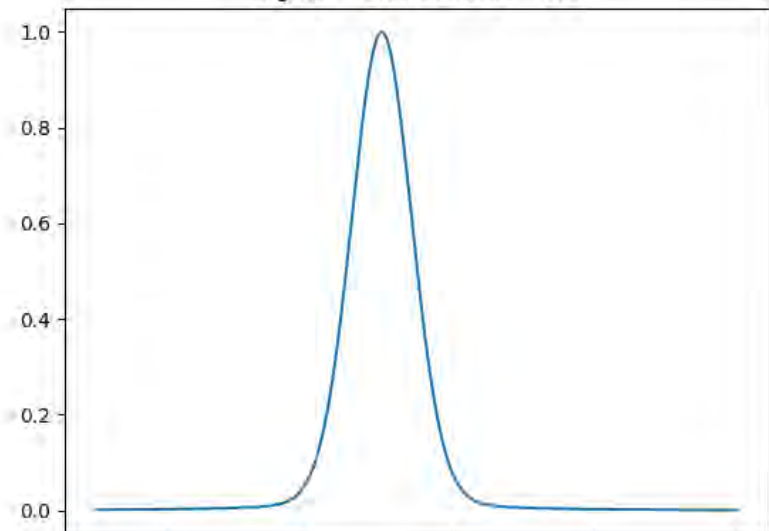
Voigt profile: Gaussian factor

Sigma = 5, Gamma = 0.5



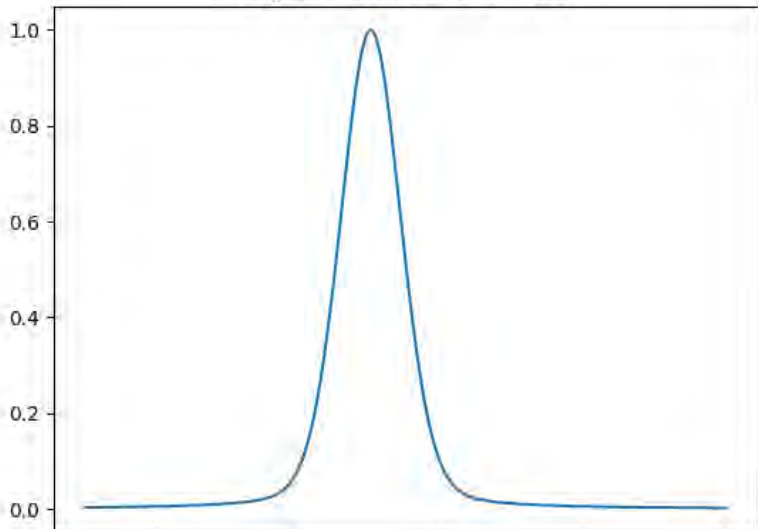
Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 0.1



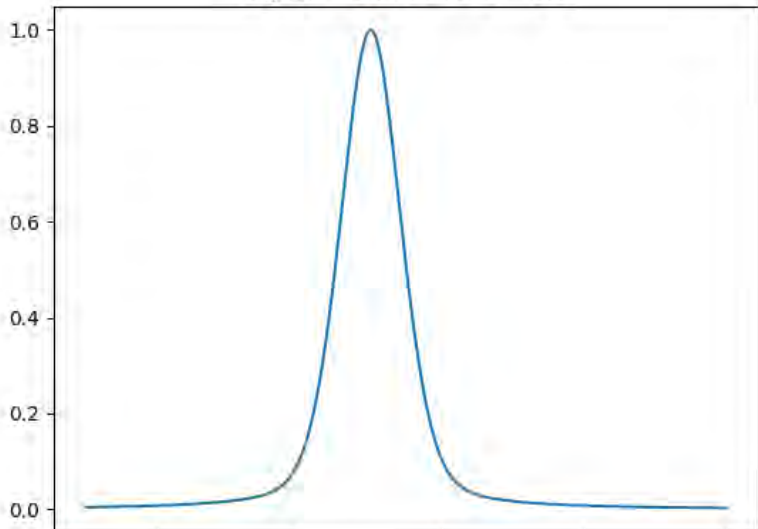
Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 0.2



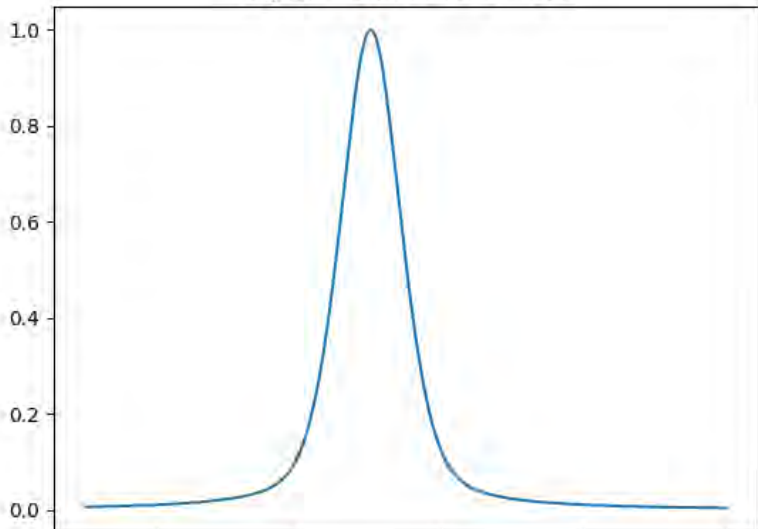
Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 0.3



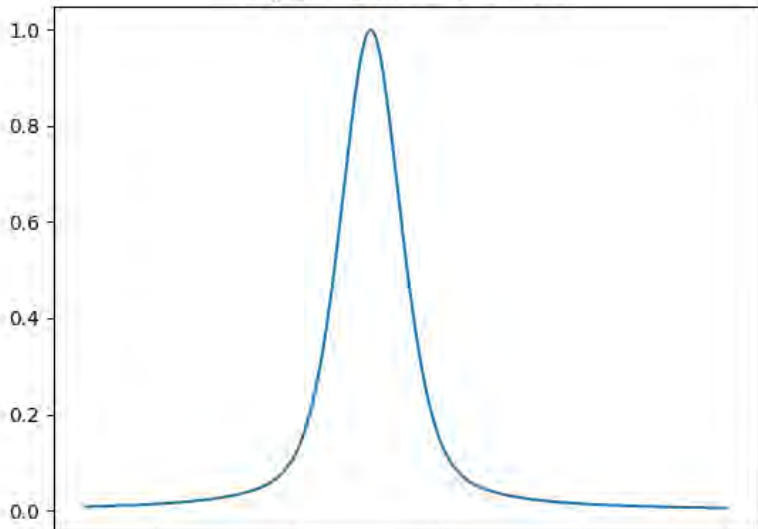
Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 0.4



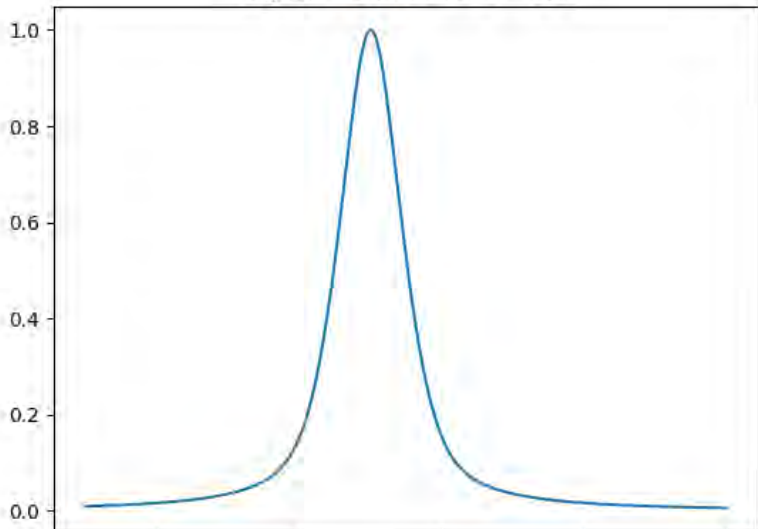
Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 0.5



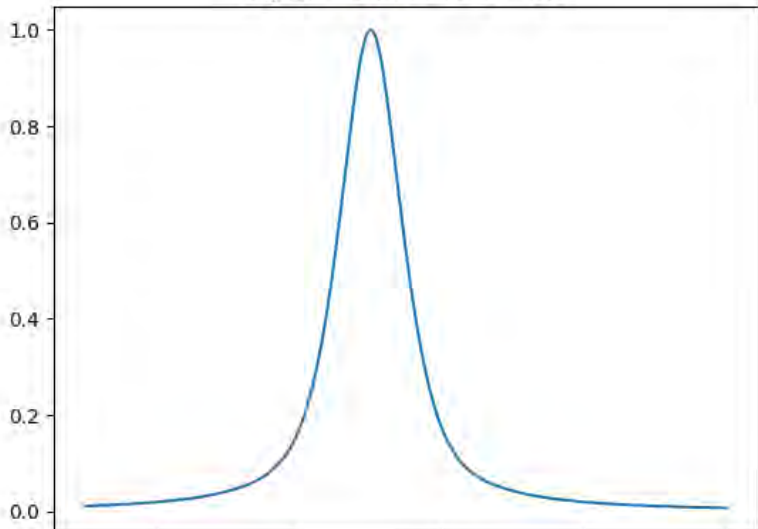
Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 0.6



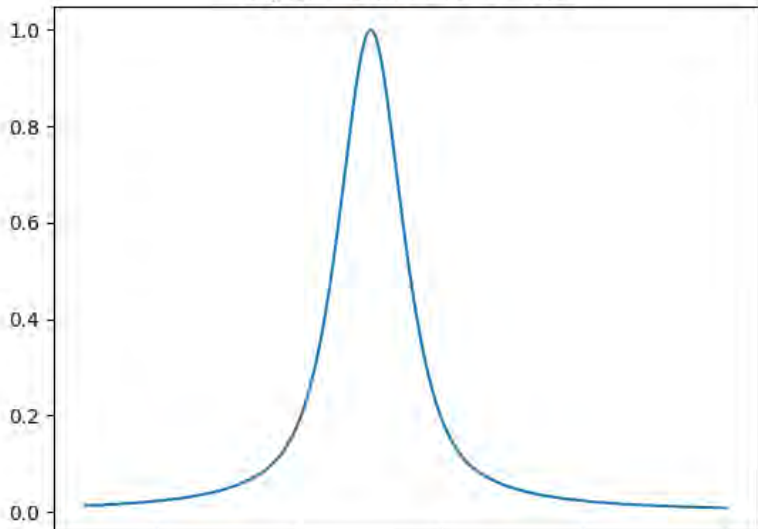
Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 0.7



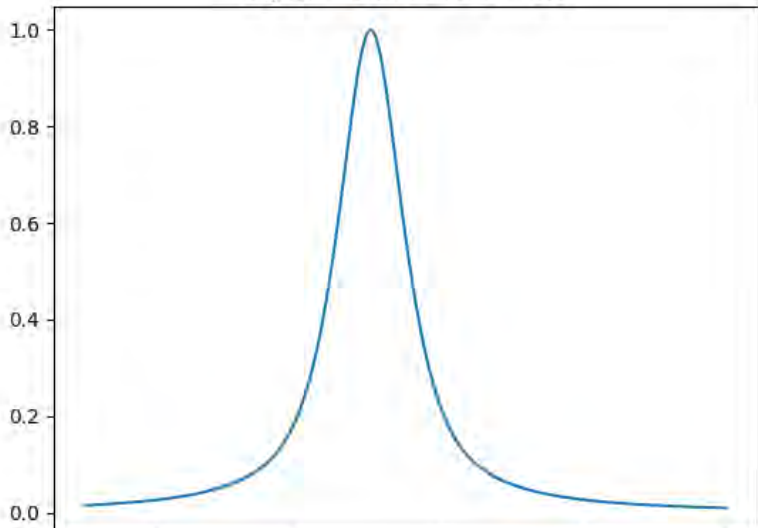
Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 0.8



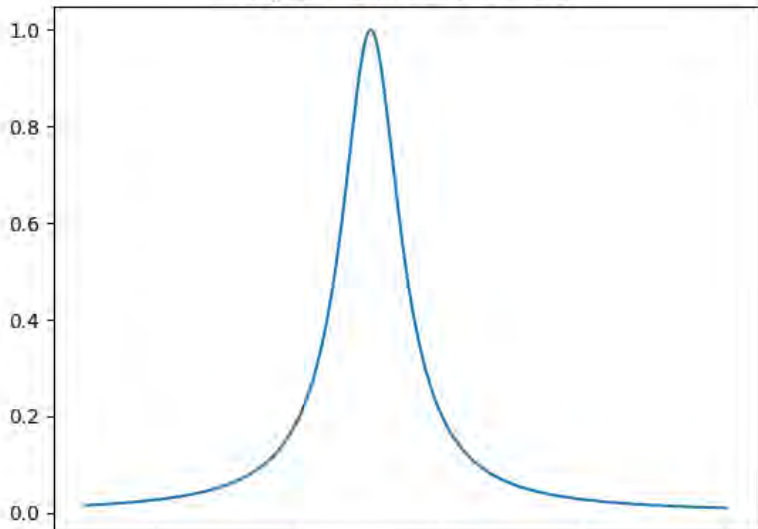
Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 0.9



Voigt profile: Lorentz factor

Sigma = 1.0, Gamma = 1.0



Equipment: Analogue vs. digital



Analogue cameras.



SDAFO = Spectral Digital Autonomous Fireball Observatory

Equipment: Analogue vs. digital (Canon EOS 6D)

- focal length of 360mm
 - 1:4.5 focal ratio
 - 180 × 240 mm photo-plate
 - resolution 23957 × 17967 px
 - 15.2 rotations/s shutter
 - 600 grooves/mm grating
 - limiting magnitude ~ -6
 - Whole night exposure time
 - dispersion 0.45 Å/pixel
 - spectral range 3500 - 6600 Å
 - (FOV $\sim 25^\circ \times 40^\circ$) × 6
 - working from 1960 to 2018
 - 240 recorded spectra
- focal length of 15mm
 - 1:2.8 focal ratio
 - 35.8 × 23.9 mm sensor size
 - resolution 5472 × 3648 px
 - no shutter
 - 1000 grooves/mm grating
 - limiting magnitude ~ -7
 - exposure time of 30s
 - dispersion 4 Å/pixel
 - spectral range 3700 - 9000 Å
 - (FOV $\sim 100^\circ \times 140^\circ$) × 2
 - working since 2015
 - 670 recorded spectra

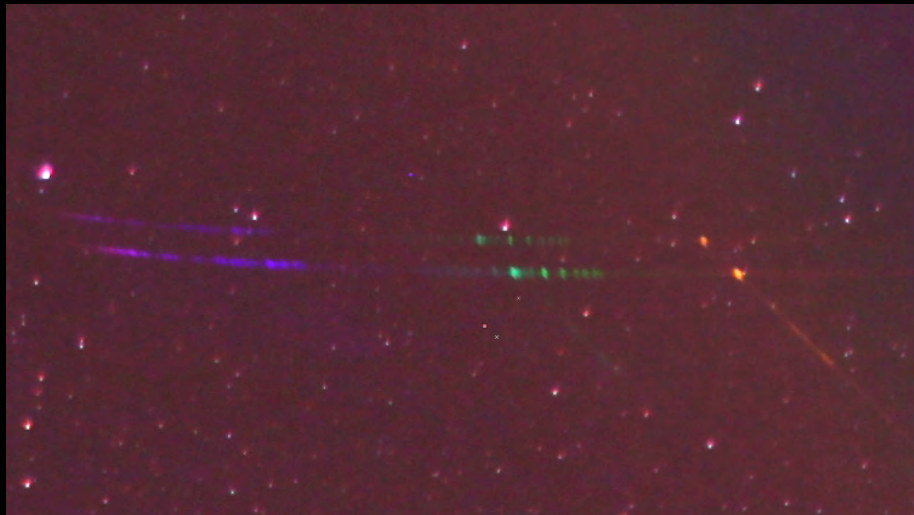
Equipment: Analogue vs. digital (Canon EOS 6D)

- focal length of 360mm
- 1:4.5 focal ratio
- 180 x 240 mm photo-plate
- resolution **23957 x 17967 px**
- 15.2 rotations/s shutter
- 600 grooves/mm grating
- limiting magnitude ~ -6
- **Whole night** exposure time
- dispersion **0.45 Å/pixel**
- spectral range **3500 - 6600 Å**
- **(FOV $\sim 25^\circ \times 40^\circ$) x 6**
- **working from 1960 to 2018**
- **240** recorded spectra
- focal length of 15mm
- 1:2.8 focal ratio
- 35.8 x 23.9 mm sensor size
- resolution **5472 x 3648 px**
- no shutter
- 1000 grooves/mm grating
- limiting magnitude ~ -7
- exposure time of **30s**
- dispersion **4 Å/pixel**
- spectral range **3700 - 9000 Å**
- **(FOV $\sim 100^\circ \times 140^\circ$) x 2**
- **working since 2015**
- **670** recorded spectra

Obtaining the spectrum from the image



Obtaining the spectrum from the image

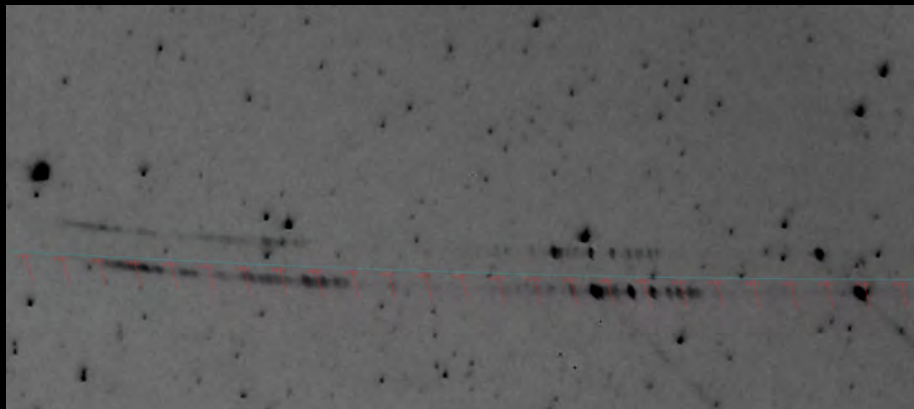


Obtaining the spectrum from the image



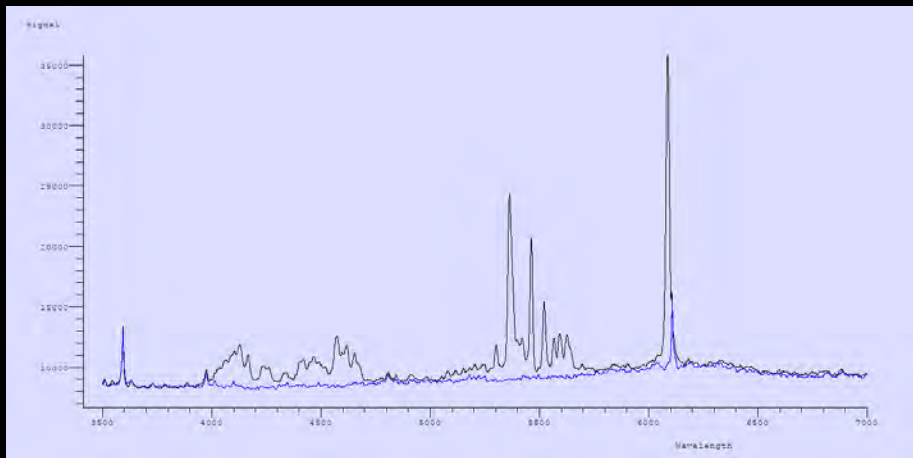
Astrometry and photometry using FishScan.

Obtaining the spectrum from the image



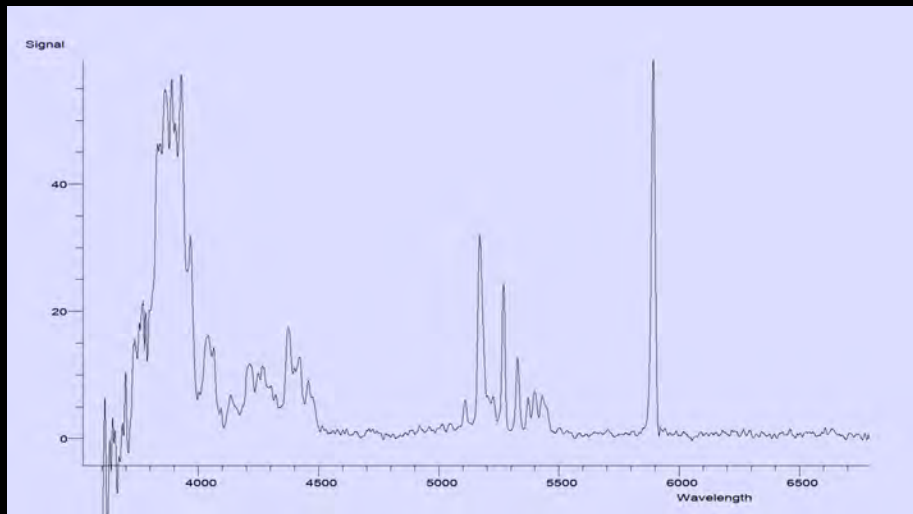
"Scanning" the spectrum using FishScan.

Obtaining the spectrum from the image



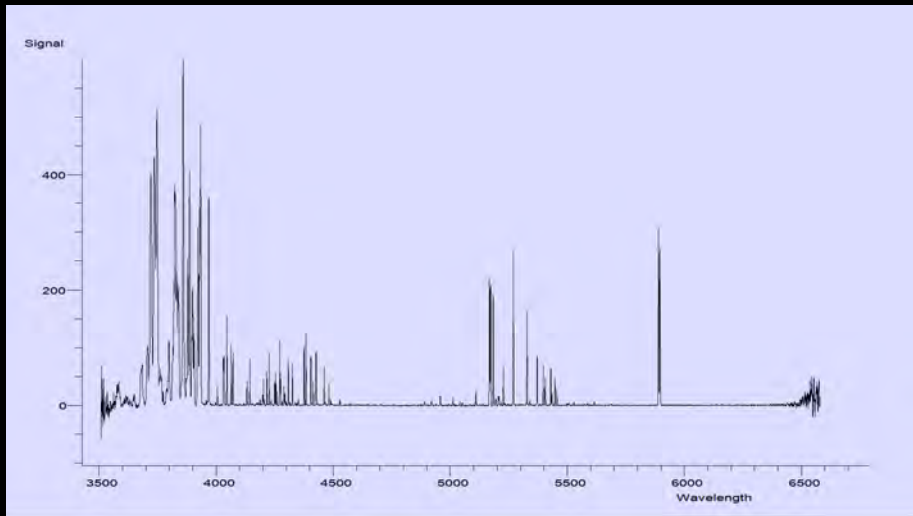
Digital spectrum with background.

Digital spectrum (calibrated)



Intensity calibrated digital spectrum.

Analogue spectrum (calibrated)



Intensity calibrated digital spectrum.

Analysing the spectrum

- Originally analysis by parts in separate software
 - Wavelength calibration
 - Spectral sensitivity calibration
 - Synthetic fit of the spectrum
 - Wavelength dependencies of the fit parameters
 - Continuum identification
 - Physical fit of the spectrum
 - Comparison with other spectra
 - **Intensity correction for position in FoV**
- New semi-automated approach using SynthFit software

FoV intensity correction (motivation)



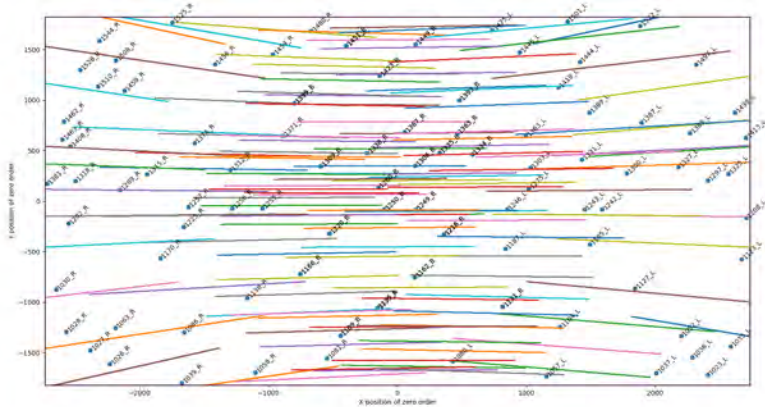
FoV intensity correction (motivation)



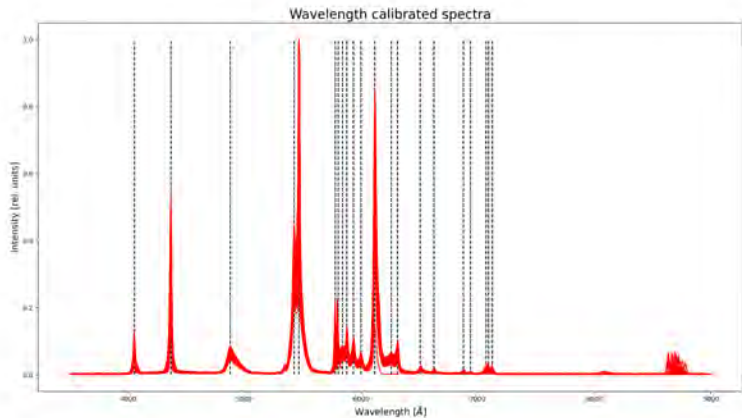
FoV intensity correction (lab spectra)



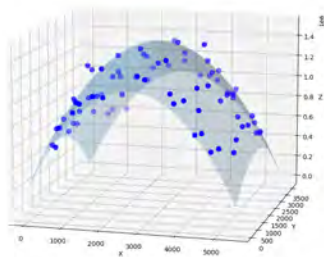
FoV intensity correction (lab spectra)



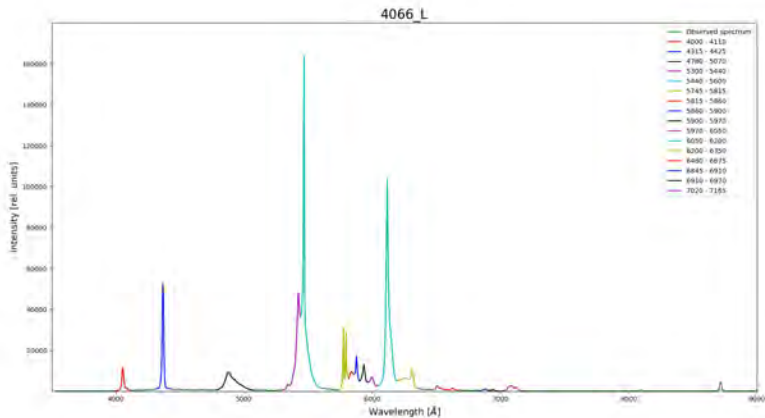
FoV intensity correction: Wavelength correction



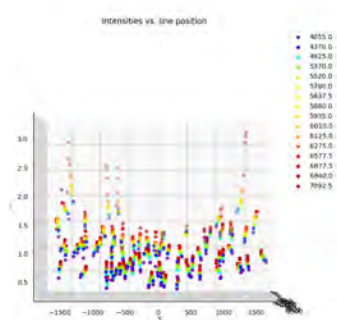
FoV intensity correction: Zero order intensity



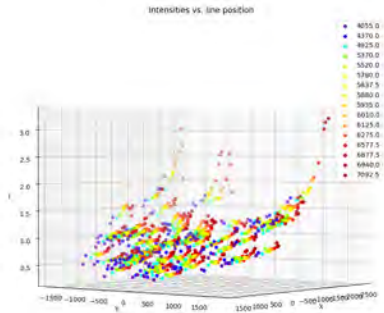
FoV intensity correction: Wavelength segments



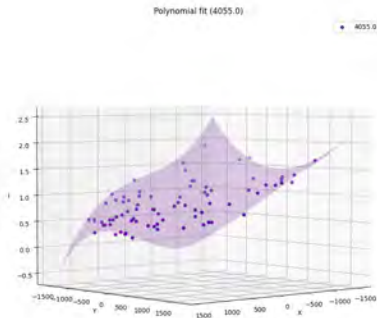
FoV intensity correction: Line intensities



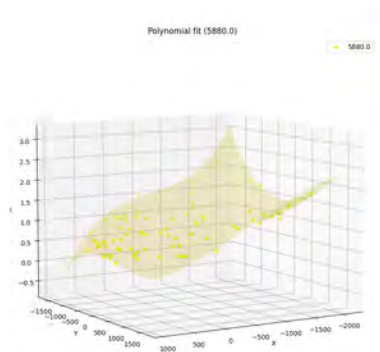
FoV intensity correction: Line intensities



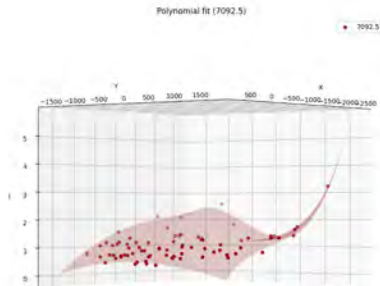
FoV intensity correction: Line intensities



FoV intensity correction: Line intensities

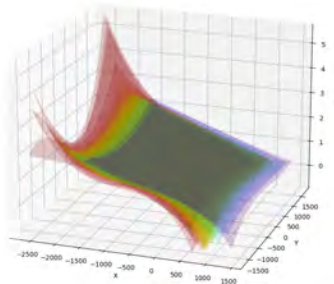


FoV intensity correction: Line intensities



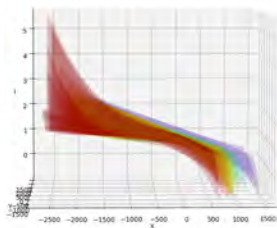
FoV intensity correction: Line intensities

Polynomial fit (7092.5)



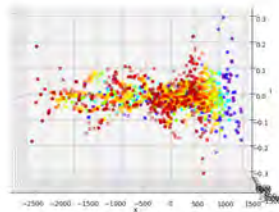
FoV intensity correction: Line intensities

Polynomial fit (7092.5)



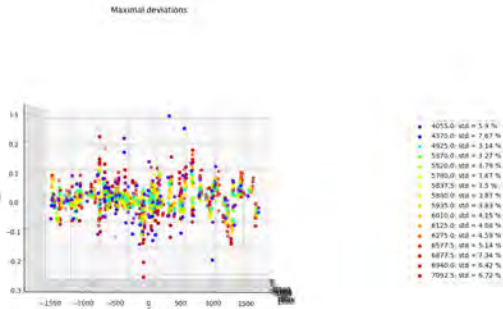
FoV intensity correction: Line intensities

Maximal deviations

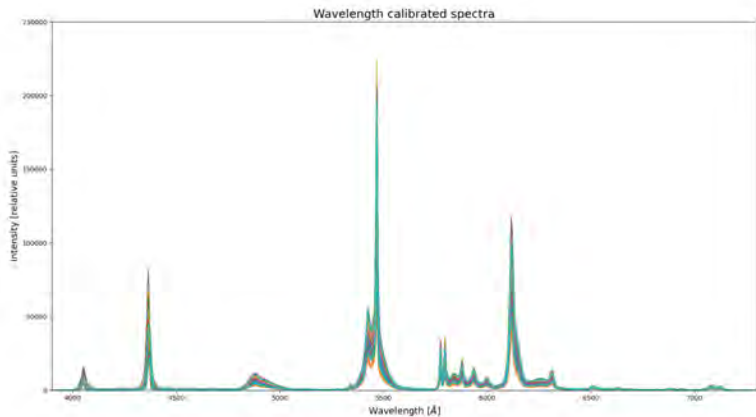


- 4055.0: $\sigma_{\text{rel}} = 3.6\%$
- 4370.0: $\sigma_{\text{rel}} = 7.67\%$
- 4925.0: $\sigma_{\text{rel}} = 3.14\%$
- 5570.0: $\sigma_{\text{rel}} = 3.27\%$
- 5520.0: $\sigma_{\text{rel}} = 4.79\%$
- 5780.0: $\sigma_{\text{rel}} = 1.67\%$
- 5837.5: $\sigma_{\text{rel}} = 1.5\%$
- 5890.0: $\sigma_{\text{rel}} = 1.87\%$
- 5935.0: $\sigma_{\text{rel}} = 1.83\%$
- 6030.0: $\sigma_{\text{rel}} = 4.15\%$
- 6125.0: $\sigma_{\text{rel}} = 4.08\%$
- 6275.0: $\sigma_{\text{rel}} = 4.59\%$
- 6577.5: $\sigma_{\text{rel}} = 5.18\%$
- 6875.0: $\sigma_{\text{rel}} = 7.34\%$
- 6940.0: $\sigma_{\text{rel}} = 6.42\%$
- 7092.5: $\sigma_{\text{rel}} = 6.72\%$

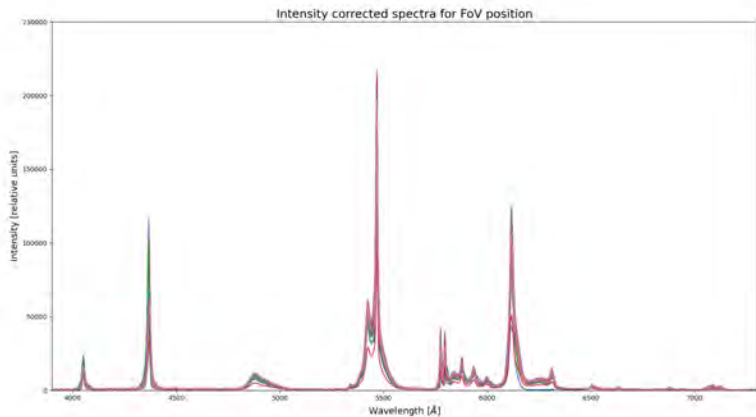
FoV intensity correction: Line intensities



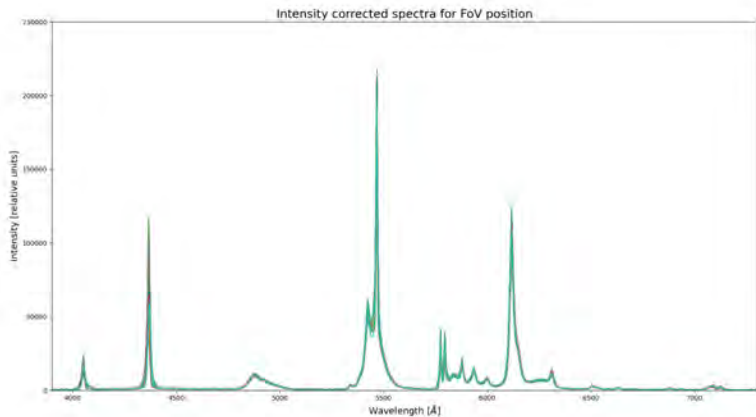
FoV intensity correction: Uncorrected



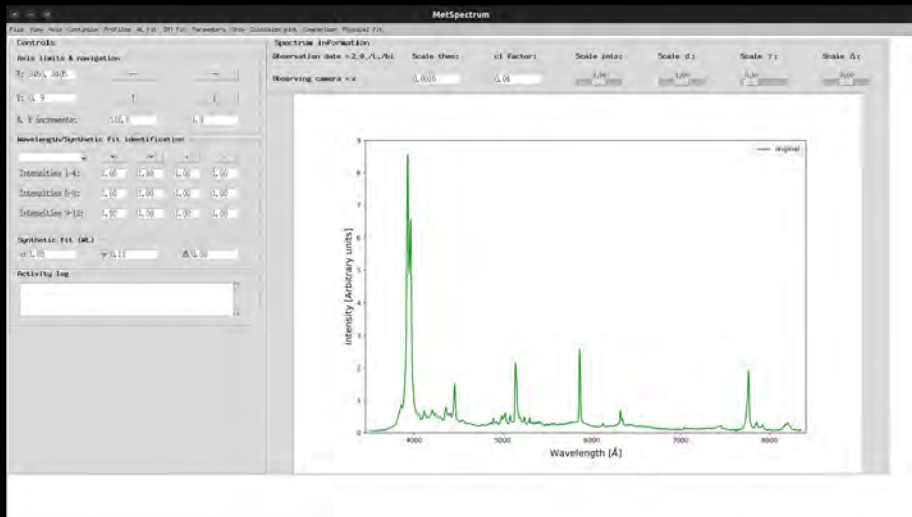
FoV intensity correction: Corrected



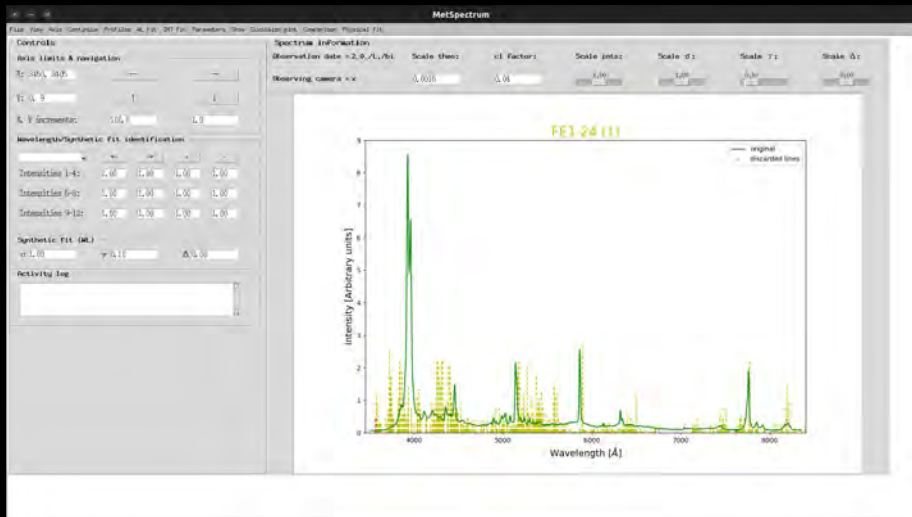
FoV intensity correction: Corrected



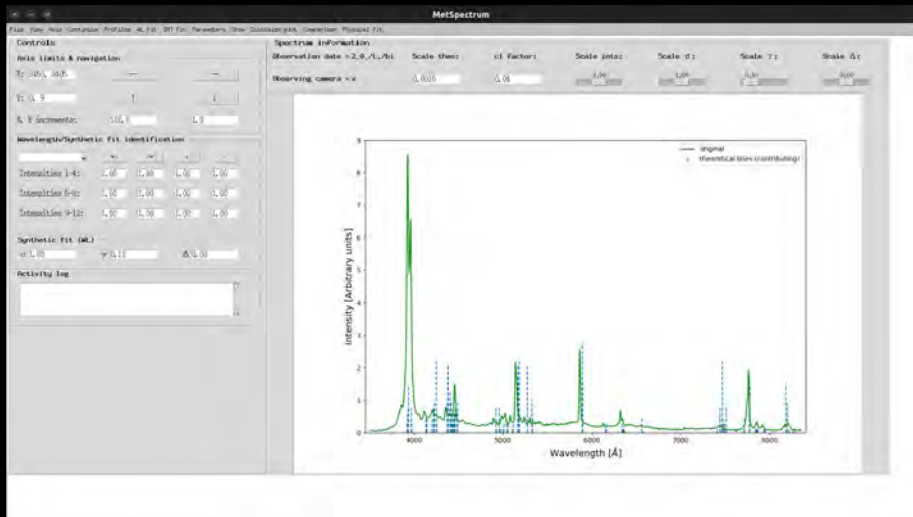
Analysing the spectrum: Loading the spectrum



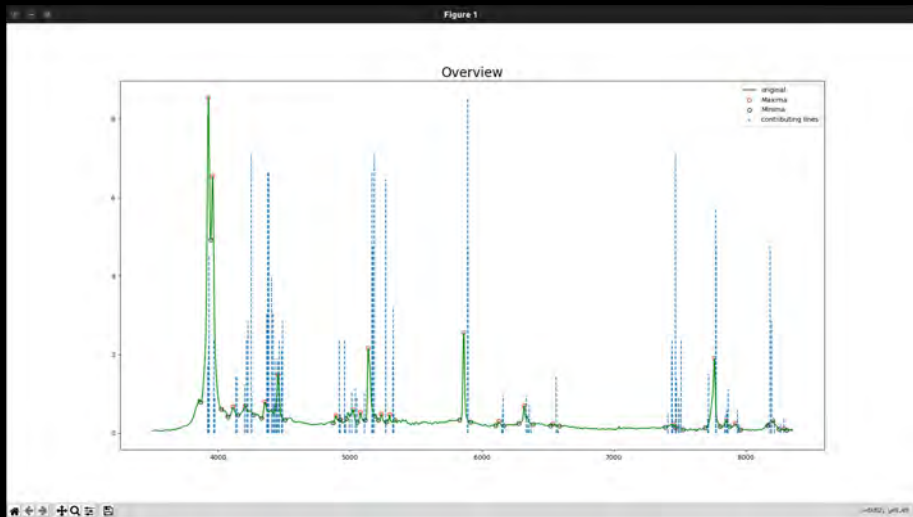
Analysing the spectrum: Loading theoretical lines



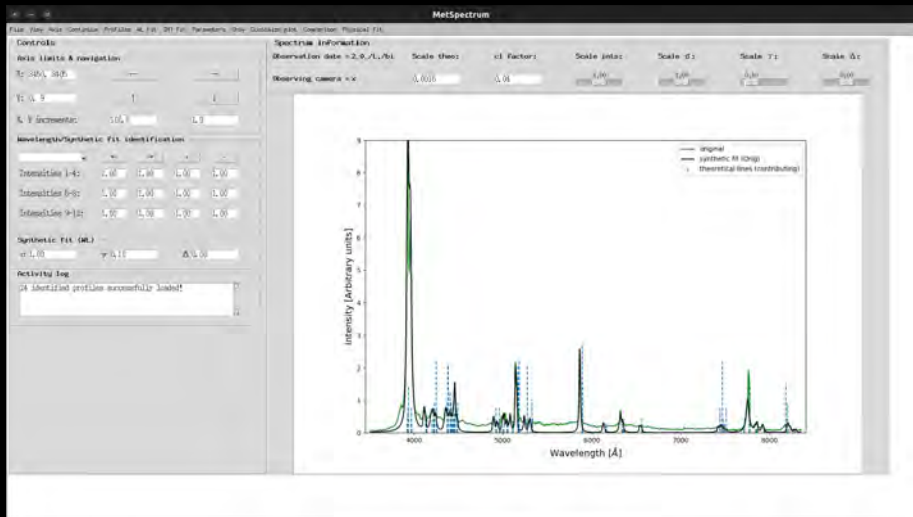
Analysing the spectrum: Contributing line selection



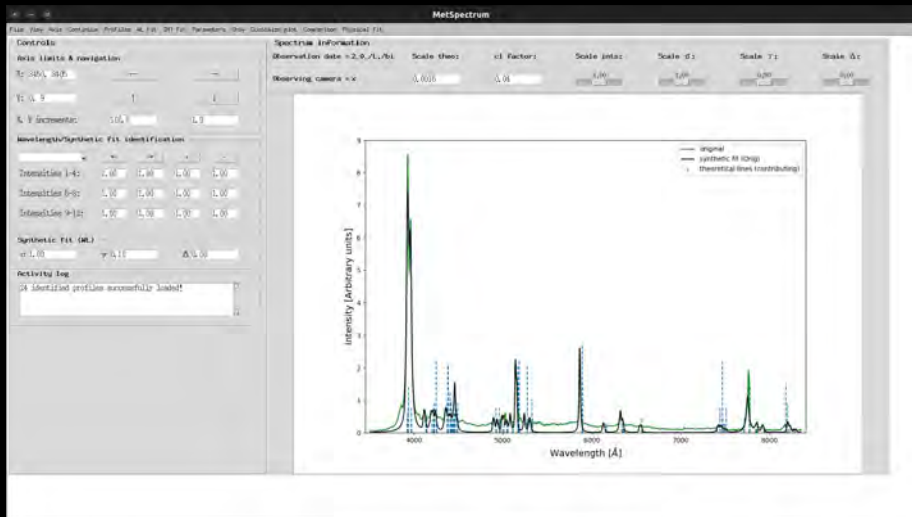
Analysing the spectrum: Identifying profiles



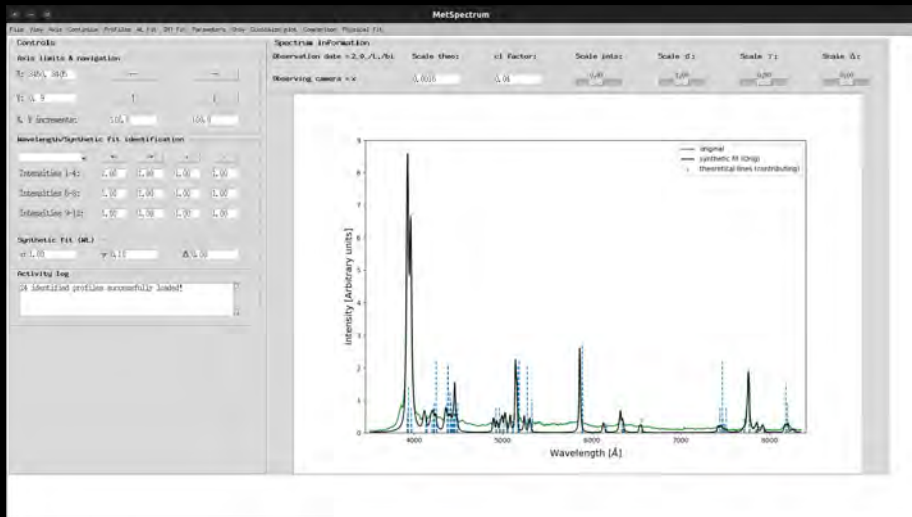
Analysing the spectrum: Automatic rough fit



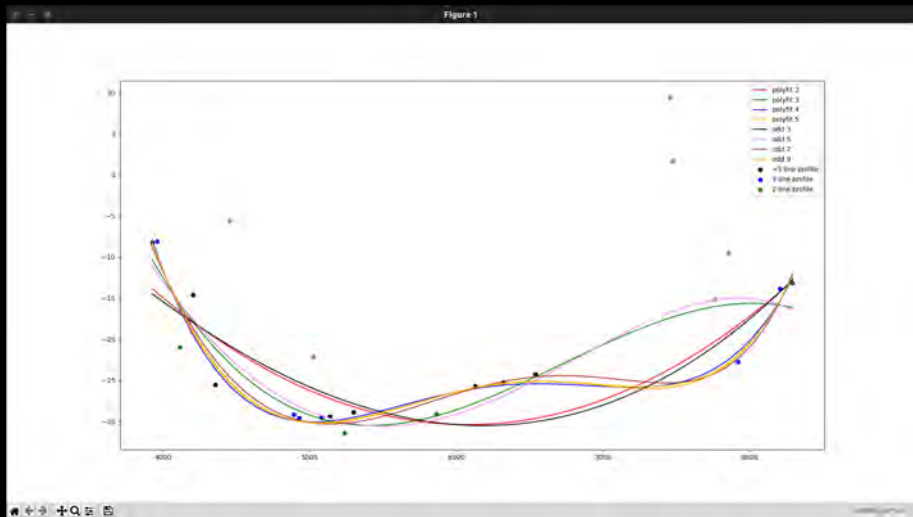
Analysing the spectrum: Accounting for overlap



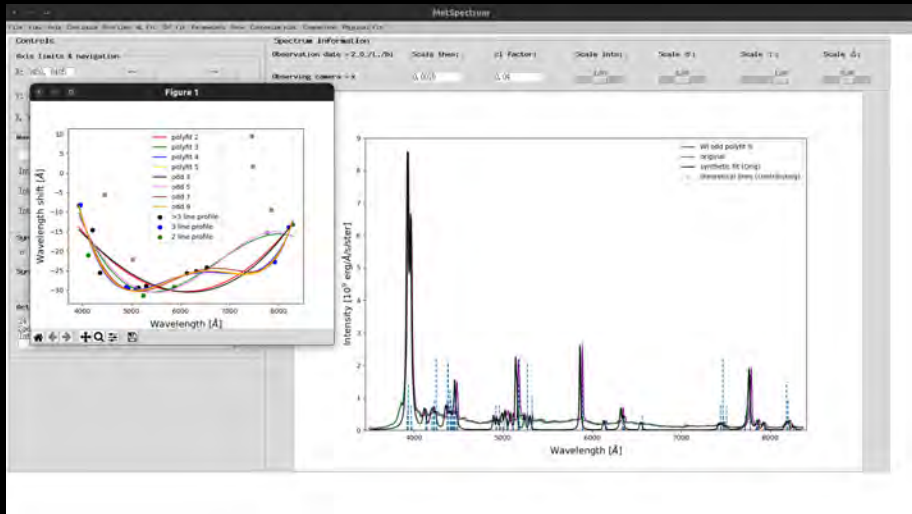
Analysing the spectrum: Manual adjustments



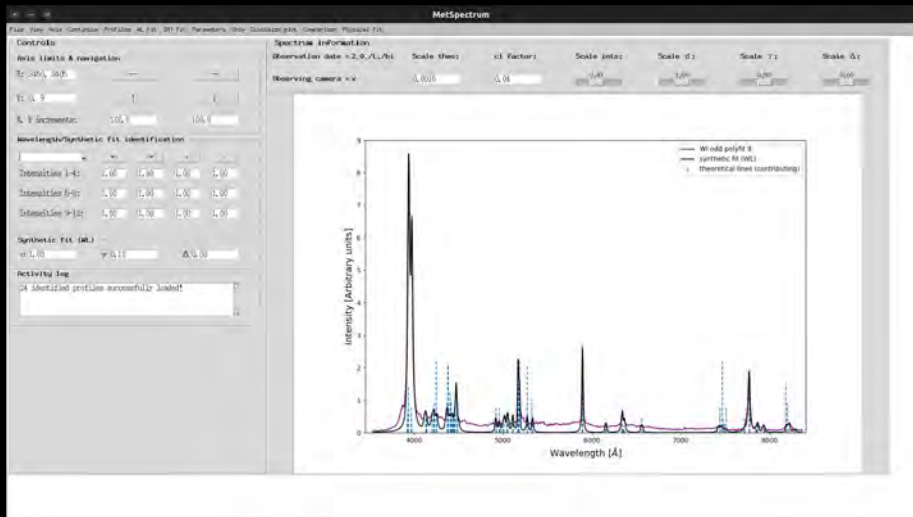
Analysing the spectrum: Wavelength calibration



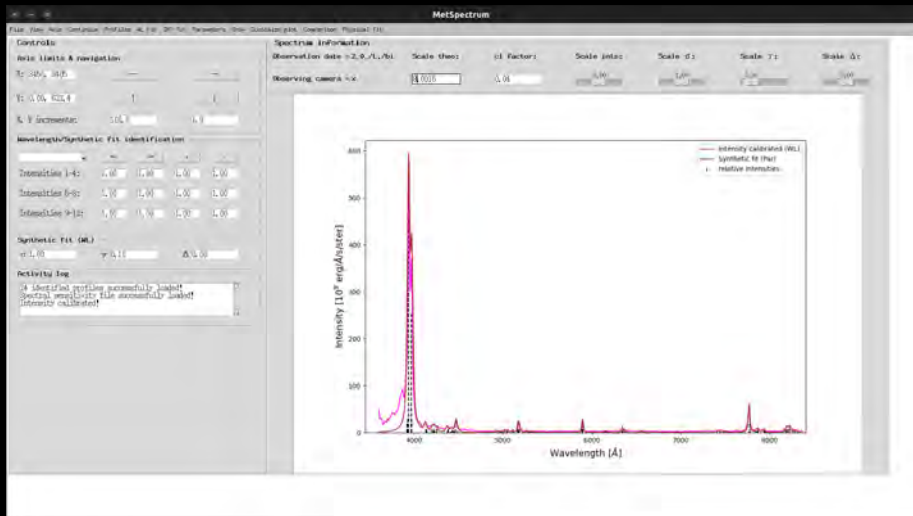
Analysing the spectrum: Selecting best fit degree



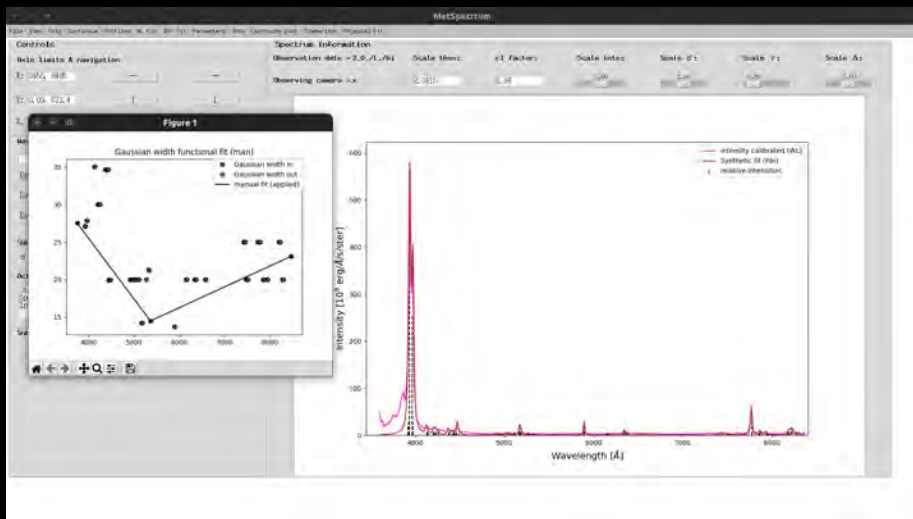
Analysing the spectrum: Applying the fit



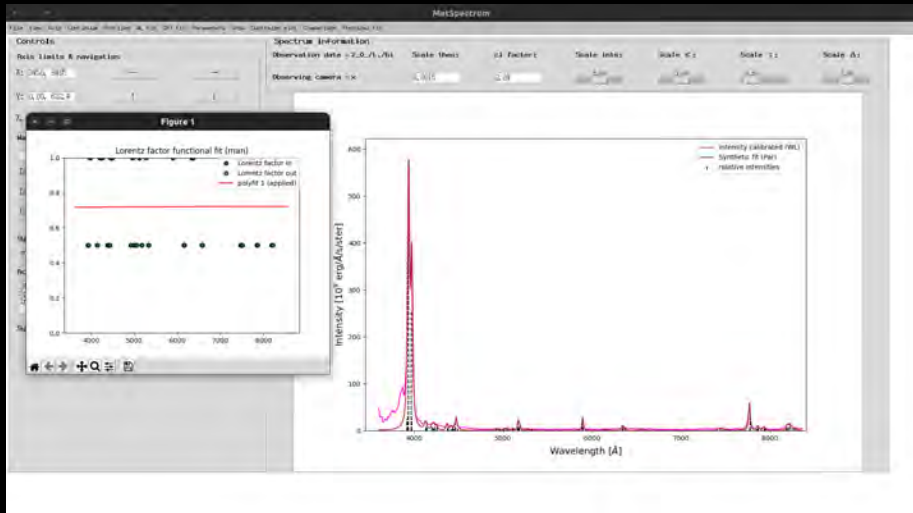
Analysing the spectrum: Spectral sensitivity calibration



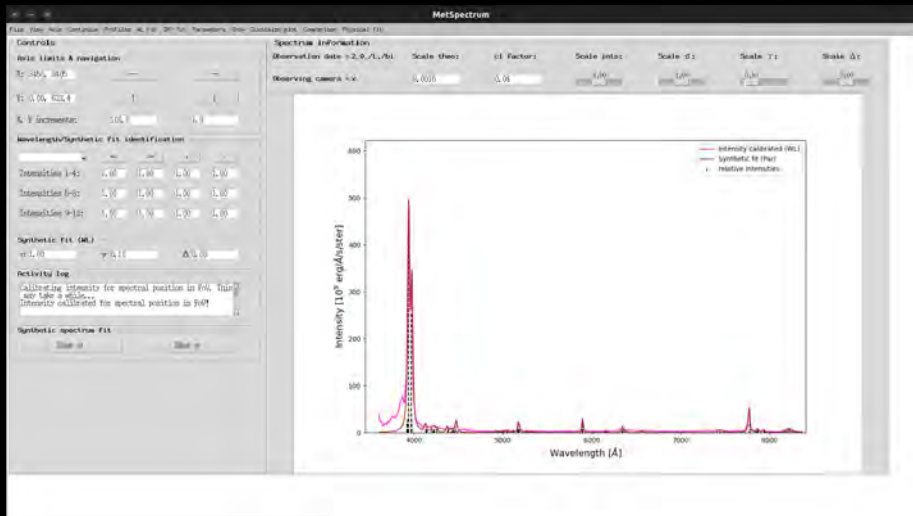
Analysing the spectrum: Gaussian factor parametrization



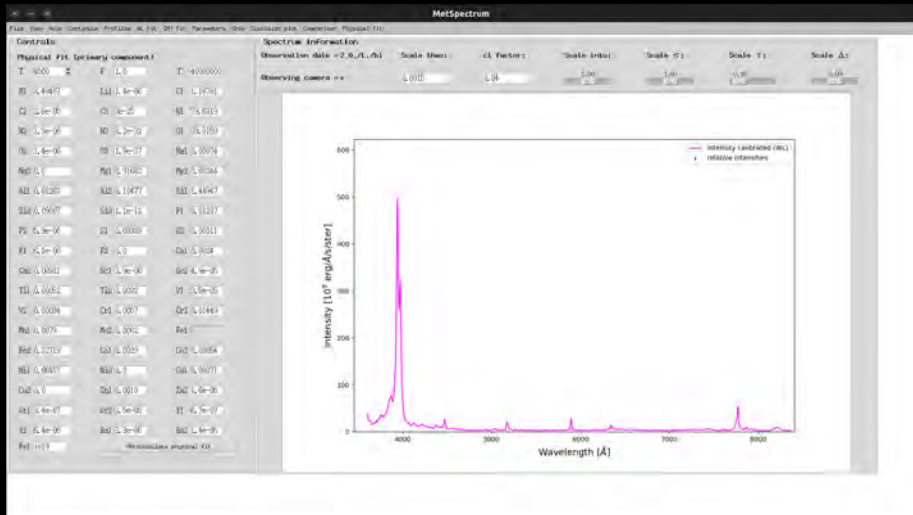
Analysing the spectrum: Lorentz factor parametrization



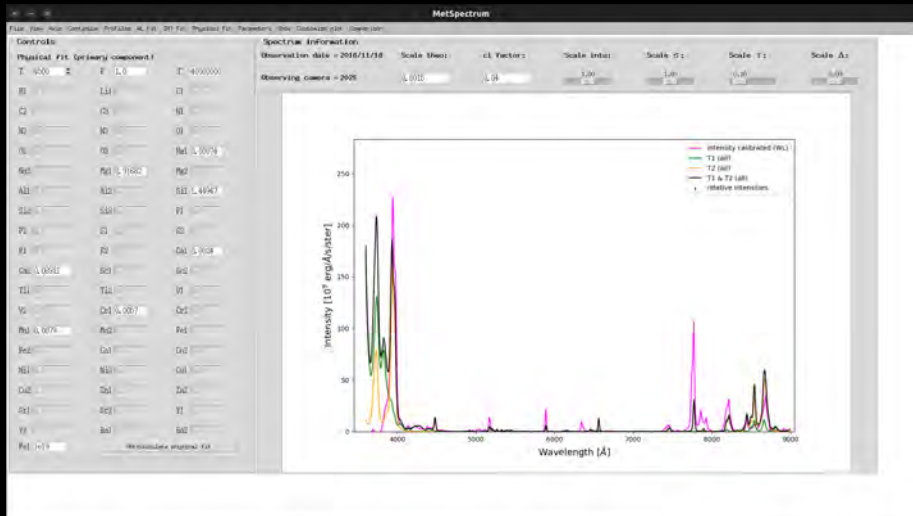
Analysing the spectrum: FoV intensity correction



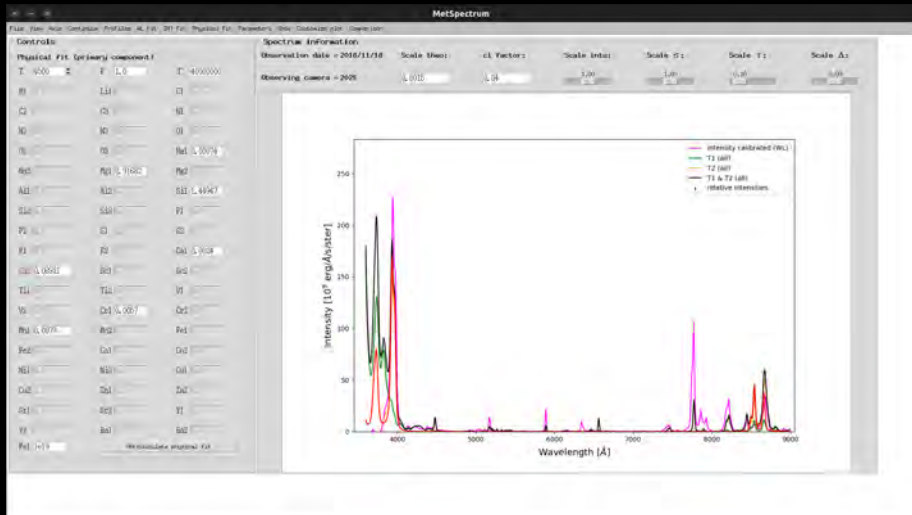
Analysing the spectrum: Physical fit



Analysing the spectrum: Physical fit



Analysing the spectrum: Physical fit



- ✓ Partial automation of the analysis process
- ✓ Wavelength calibration
- ✓ Lorentz and Gaussian factor dependency on wavelength
- ✓ Continuum identification
- ✓ Differences in spectra with different FOV geometry
- ✓ Physical fit of the spectrum
- ✗ Spectral sensitivity
- ✗ Ionization correction

- 1 Borovička, J. 1994. Two components in meteor spectra. *Planetary and Space Science*, 42, 145–150.
- 2 Borovička, J. 1993. A fireball spectrum analysis. *Astronomy & Astrophysics*, 279, 627–645.
- 3 Borovička J., Spurný P., Shrbený L., New spectroscopic program of the European Fireball Network Proceedings of the International Meteor Conference, Pezinok-Modra, Slovakia, 2018 August 30 – September 2, Eds.: R. Rudawska, J. Rendtel, Ch. Powell, R. Lunsford, C. Verbeeck, A. Knöfel, pp. 28-32 (2019)
- 4 https://www.aps.anl.gov/files/APS-Uploads/SECTOR8/8-ID/linefit_manual.pdf