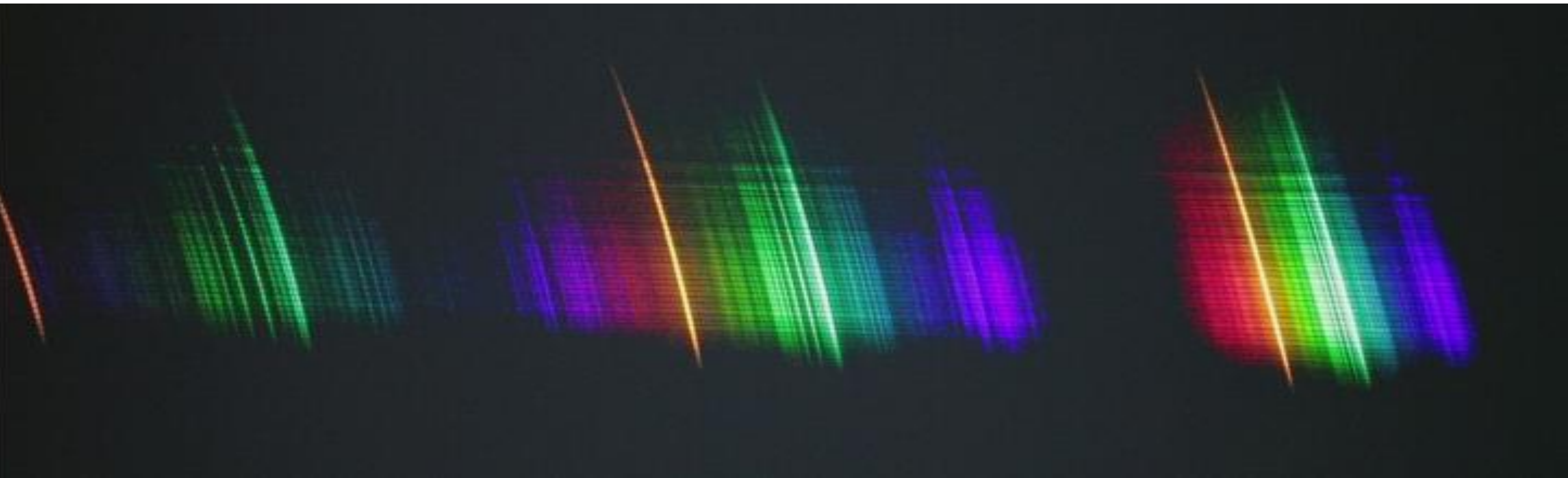
Fachgruppe Meteorastronomie

Meteor Spectroscopy, Falera, 11. 6. 2022

Martin Dubs, images by Koji Maeda

SAG, FMA

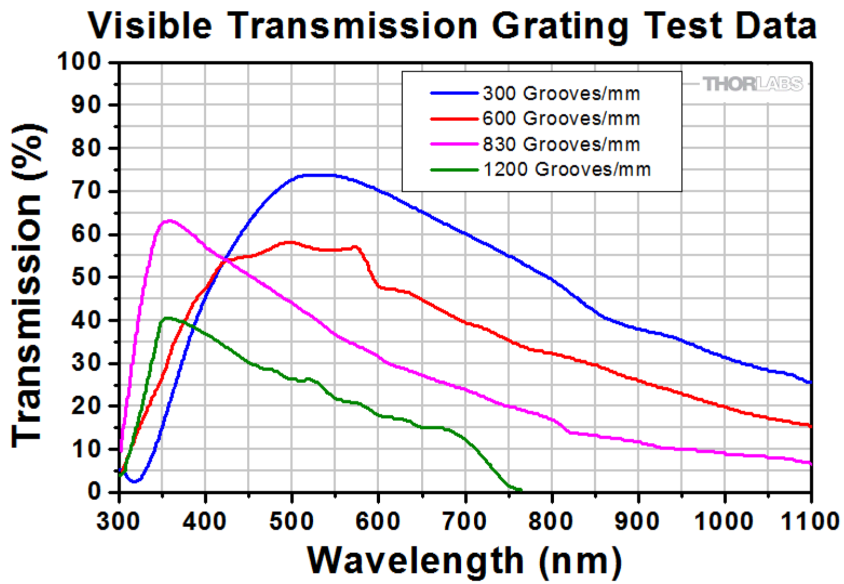


Content

- Hard- Software
- Wavelength calibration
- Processing with Python
- Improvements since last meeting
- Results
- Summary
- Live demo, Python script m_spec.py

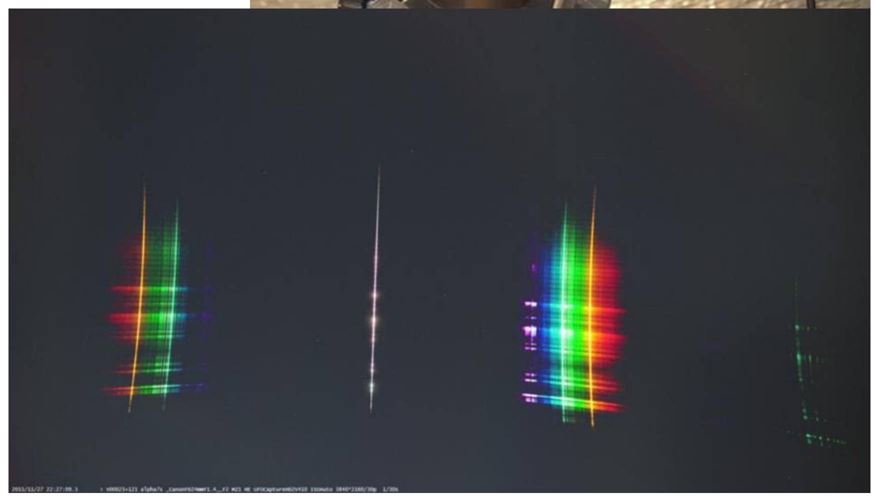
Hardware

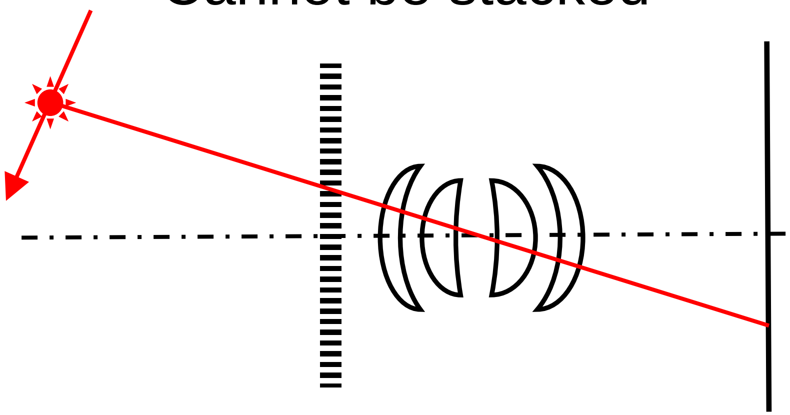
- Watec 902H2 ult. Computar HG2610AFCS-HSP F/1 2.6mm fl
- The Imaging Source **DMK 33GX249,** 1920x1200,
  Kowa LM16HC f: 16mm F/1.4 Field of view horizontal: 39°
- 2nd camera with transmission grating for spectroscopy Thorlabs 600 L/mm



Starting point

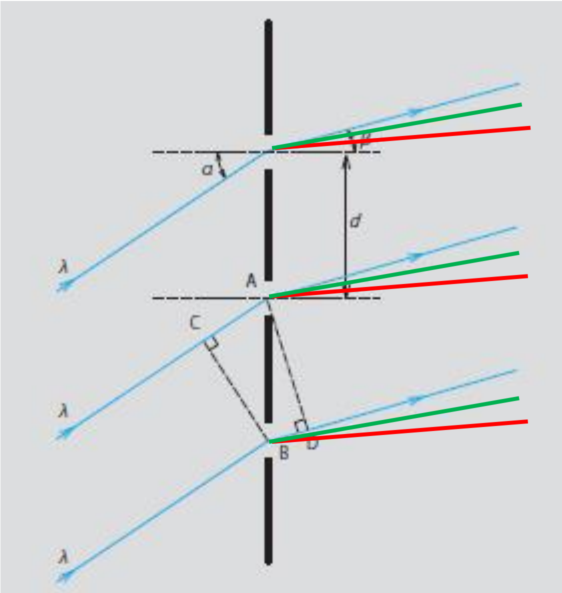
- Video camera with wide angle lens
- Transmission grating
  - mounted perpendicular to optical axis!
- Problem:
  - Moving meteor
  - Curved spectra with nonlinear dispersion
  - Cannot be stacked





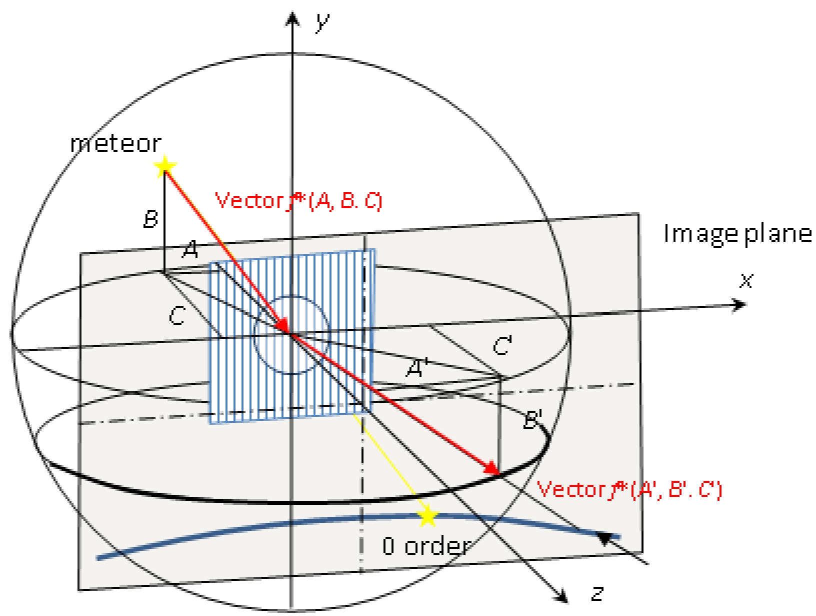
Spectrograph, theory

- Video camera with transmission grating in front of lens
- Grating equation:
  - **m * λ * G = (sin α - sin β) * cos γ**
  - m: grating order, G: grating lines / mm
  - λ: wavelength
  - α, β: angle of incidence, transmitted beam
    γ: cross, out of plane angle
- Inverse dispersion per pixel:
  dλ/dx = (cos β cos γ)/(m*G*f)*p (p: pixel size)
  - Example: f = 7 mm, p = 8.6 µm, G: 600L/mm β = 0 → dλ/dx = 2.1nm/pixel



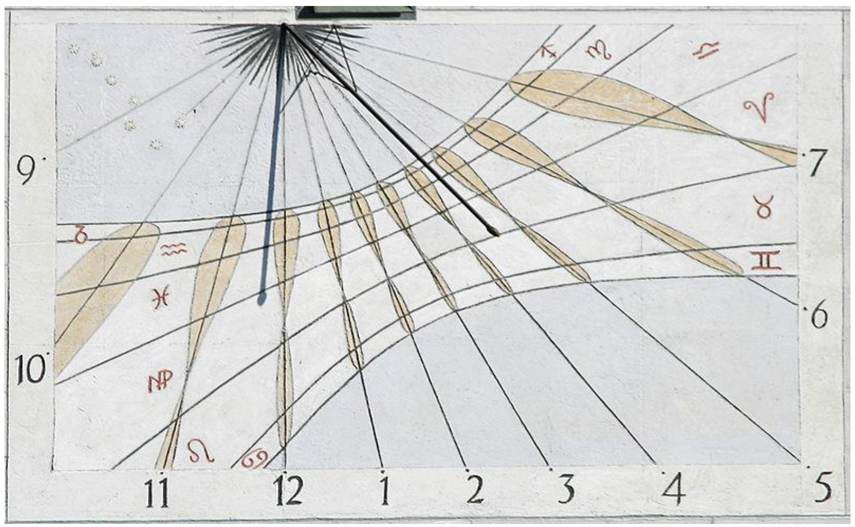
Vector theory wavelength calibration

- Grating in front of lens perpendicular to optical (z-)axis
- Unit vector (A B C) for incident direction
- Diffracted beam
  $A' = A + m\lambda G$ *(x-axis)*
  $B' = B$ *(y-axis)*
  $C' = \mathrm{sqrt}(1 - A'^2 - B'^2)$
- Spectrum on CCD plane
  - Nonlinear dispersion
  - Hyperbolic curvature
- Spectrum straight linear in A',B'

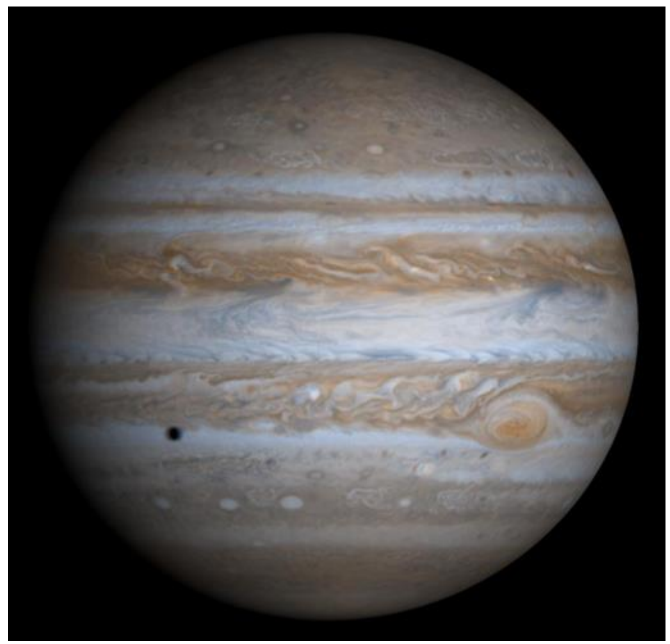


Gnomonic and orthographic projection

- Gnomonic, TAN
  - R = f*tan(ρ)
  - Great circles → straight
  - Optimum for path, radiant
  - Latitude circles → hyperbola

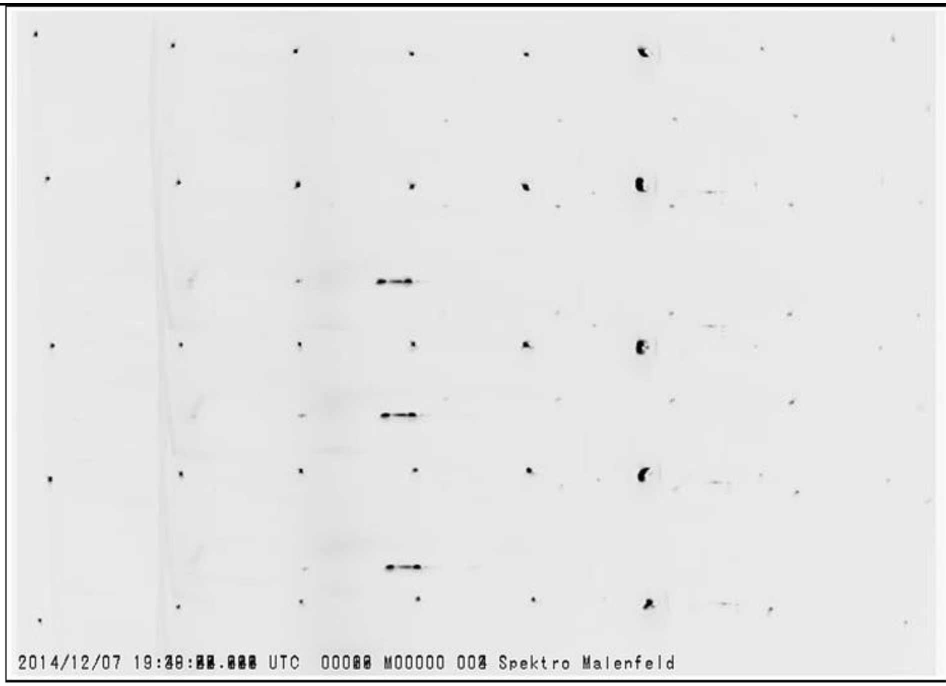


- Orthographic, SIN
  - R = f*sin(ρ)
  - Great circles →ellipses
  - Latitude circles → straight
  - Optimum for spectroscopy

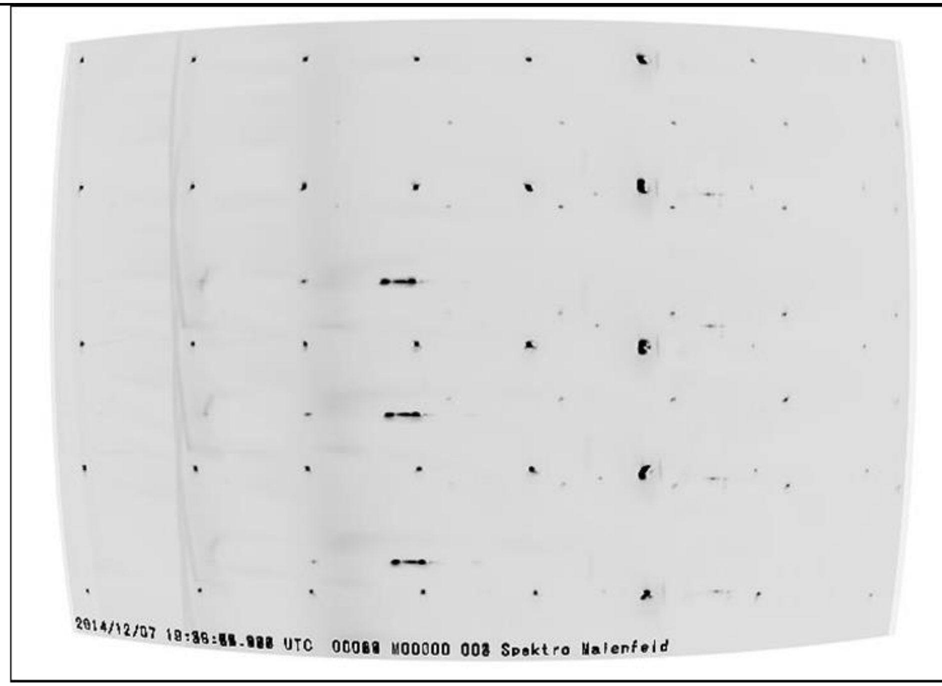


Calibration spectrum HeNe laser

- HeNe laser λ = 633 nm, f = 4 mm, grating 300L/mm
- Fit with polynom r = r' * [1 + 3.94E-07*r'2 + 2.01E-12*r'4]
- Fit center x_0, y_0

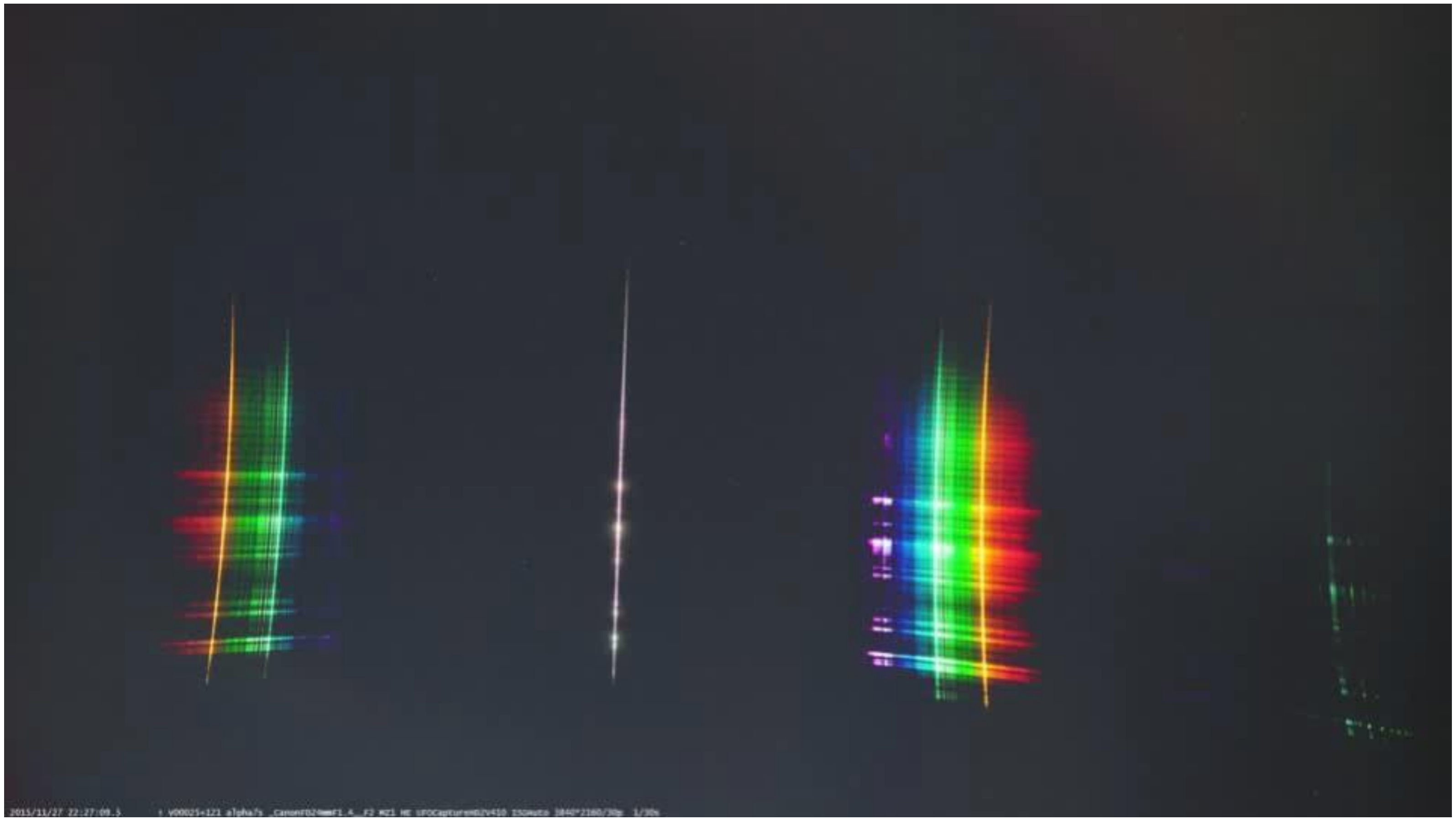


Composite spectra original

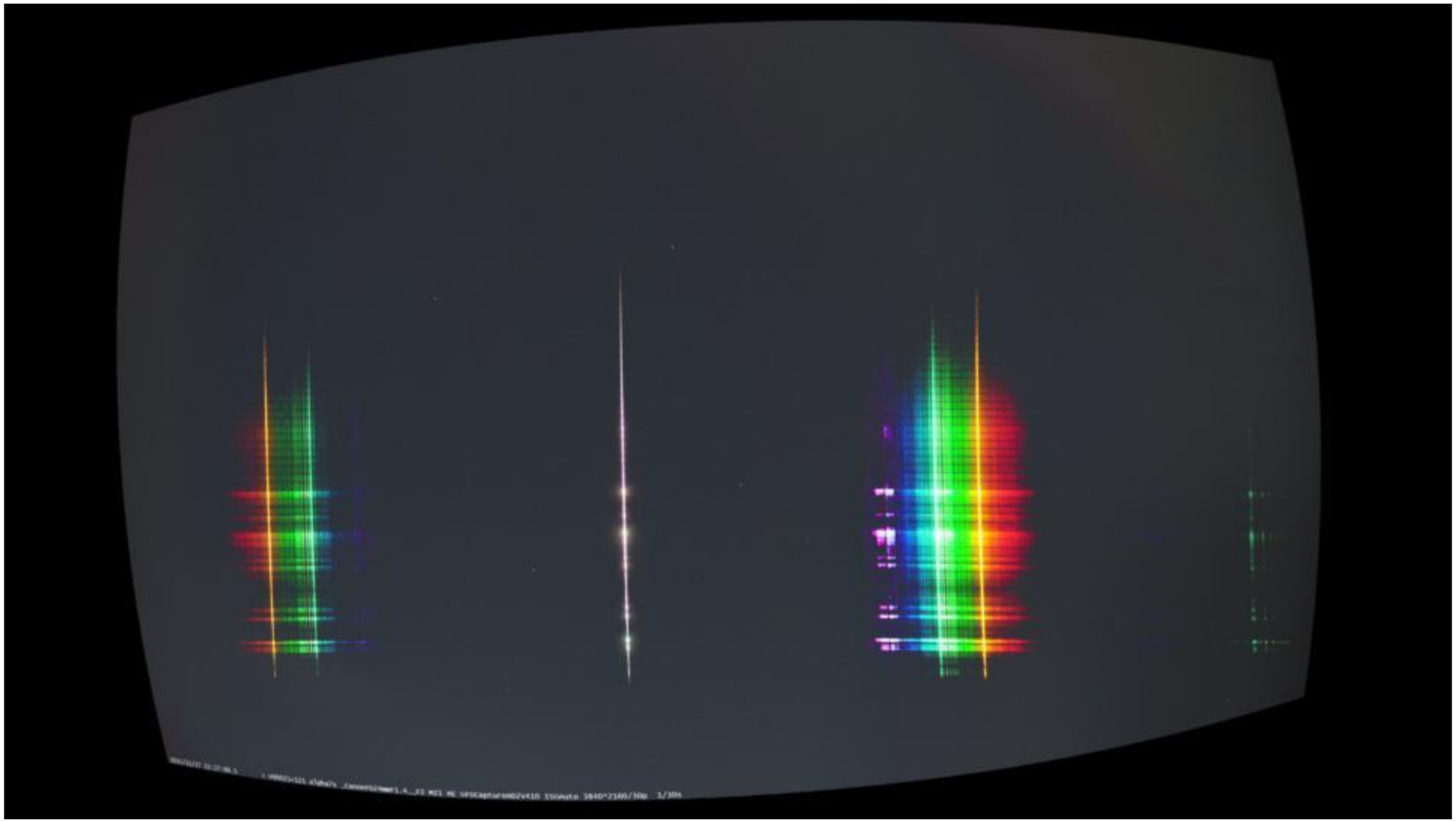


After applying transformation

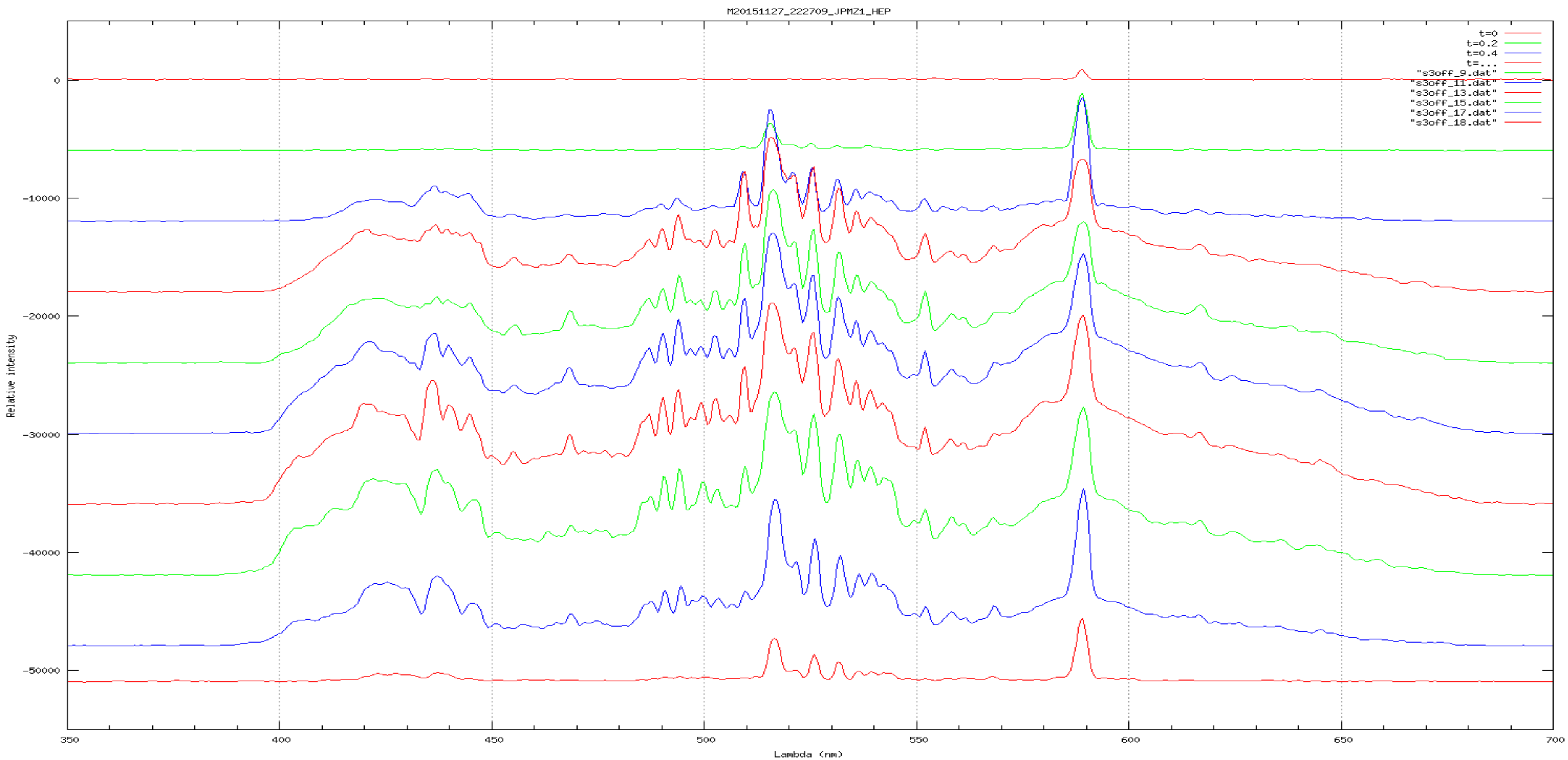
Orthographic transformation, original



Orthographic transformation, result



Extraction of spectra



Full processing, using different software

- Image extraction with VirtualDub
- preprocessing:
  - Background subtraction (IRIS)
  - Image transformation (ImageTools by Peter Schlatter)
  - Stacking of spectra (IRIS)
- Extract spectrum, calibrate wavelength (SpectraTools)
- (correction of instrument response, ISIS)
  - Grating efficiency
  - Camera spectral sensitivity (lens, CCD)
  - Atmospheric transmittance

} instrument response

Meteor spectrum processing

- Moving meteor requires special treatment of spectra
  - Nonlinear curved spectra, dispersion varies with meteor position
  - Linear spectra after orthographic transformation
  - Standard spectroscopy software only partially useful
  - Combination of different software required
- New approach: processing spectra with Python script
  - One script for laser calibration and spectrum extraction
    video file → plot of wavelength calibrated meteor spectrum
- For info see:
  https://meteorspectroscopy.org/2020/03/27/meteor-spectra-analysis-new-version/ (see more under recent posts on this page)

Why Python

- it contains all the necessary tools to do the analysis
  - Image processing
  - Astronomical packages (FITS-format)
  - Fitting algorithms (peak positions, least square fit)
  - Plotting
- it finds widespread use in the astronomy community (replaces IRAF, MIDAS)
- it is free
- it runs on different platforms

Laser calibration

- Script for least square fit of laser spectra
  - Set initial parameters
  - Load image
  - Mark different orders
  - Least square fit
  - Save results to *.ini file

Run calibration

- Mark laser lines:

- Fit equation:
  - Calculate in polar coordinates
  - Radial transformation to orthographic projection
    r = r’ * (1 + a3*r’^{2} +a5*r’^{4}) (includes lens distortion)
- Results:
  - x00, y00: coordinates of optical axis
  - rot: angle of rotation of spectra
  - disp0: dispersion [nm/pixel]
  - a3, a5: radial transformation parameters
  - rmsx, rmsy: fit errors

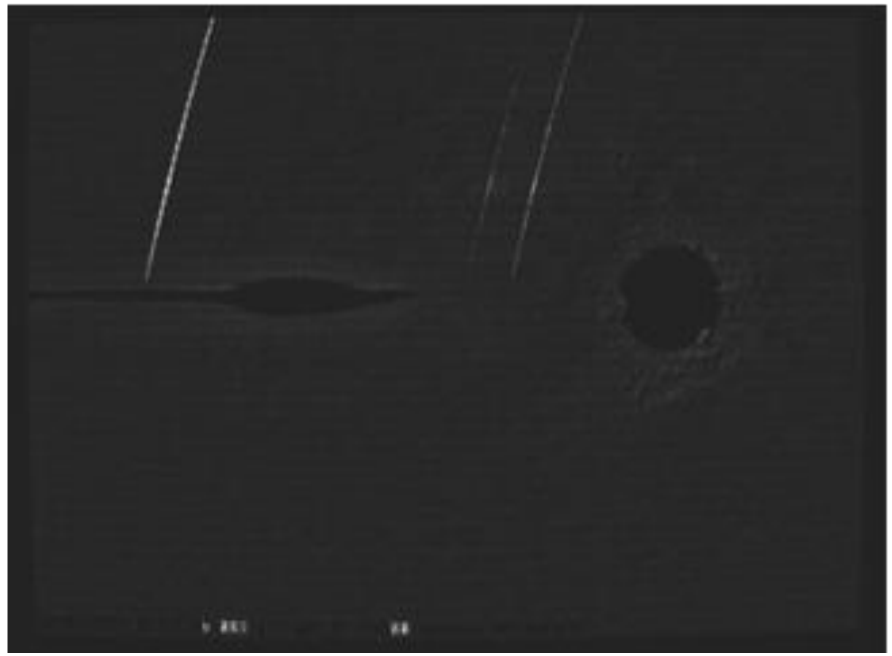
Meteor spectra processing with Python

- Processing:
  - Image extraction from video file
  - Preprocessing with dark subtraction
  - Image transformation (and flat field correction)
  - Stacking (tilt, slant correction)
  - Wavelength calibration
  - Plotting raw spectrum, save data
- Spectrum analysis
  - Instrument response
  - Line intensities (Na, Mg, Fe- ratios)

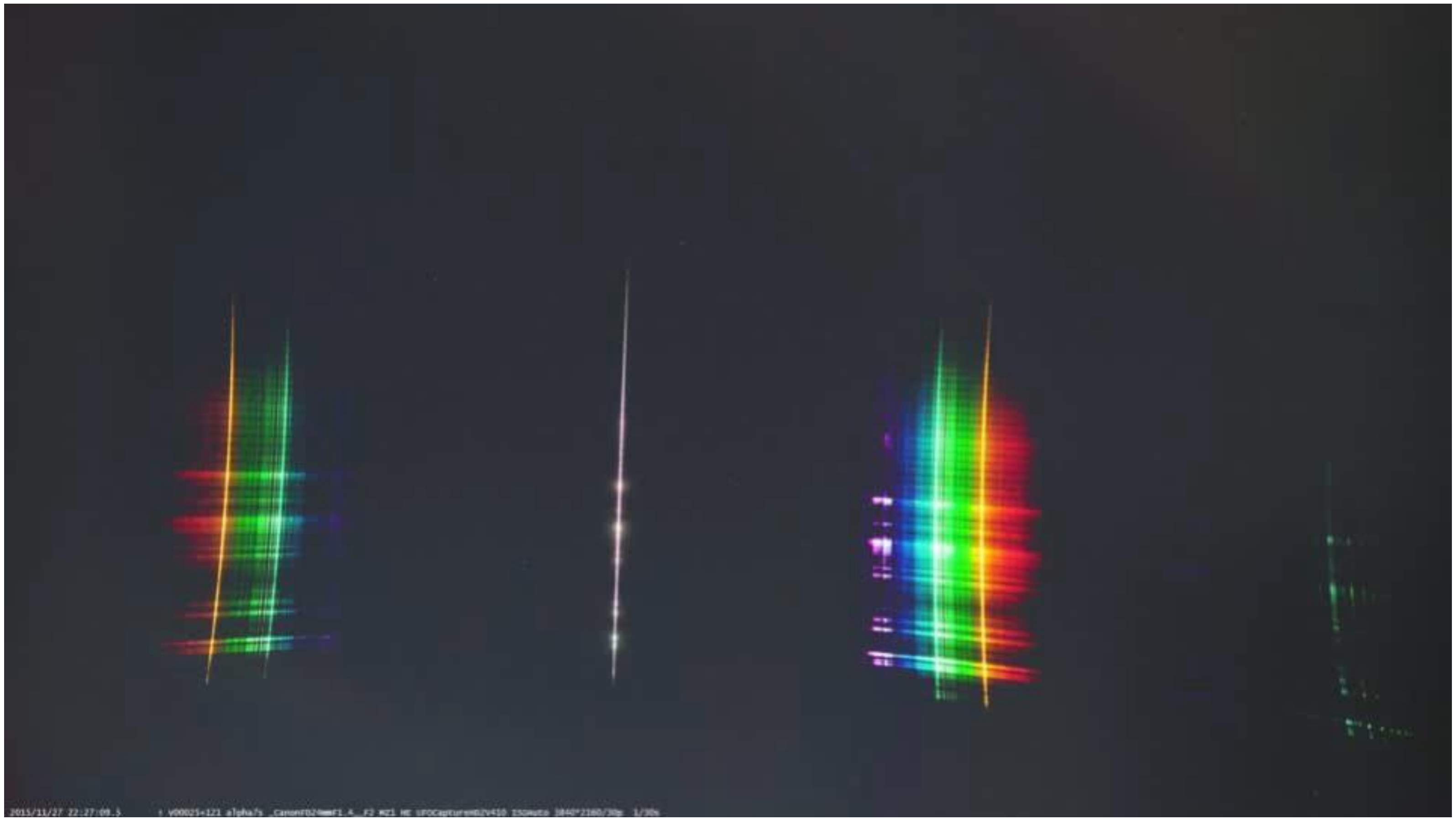
Preprocessing with Python

- Before background subtraction with moonlight

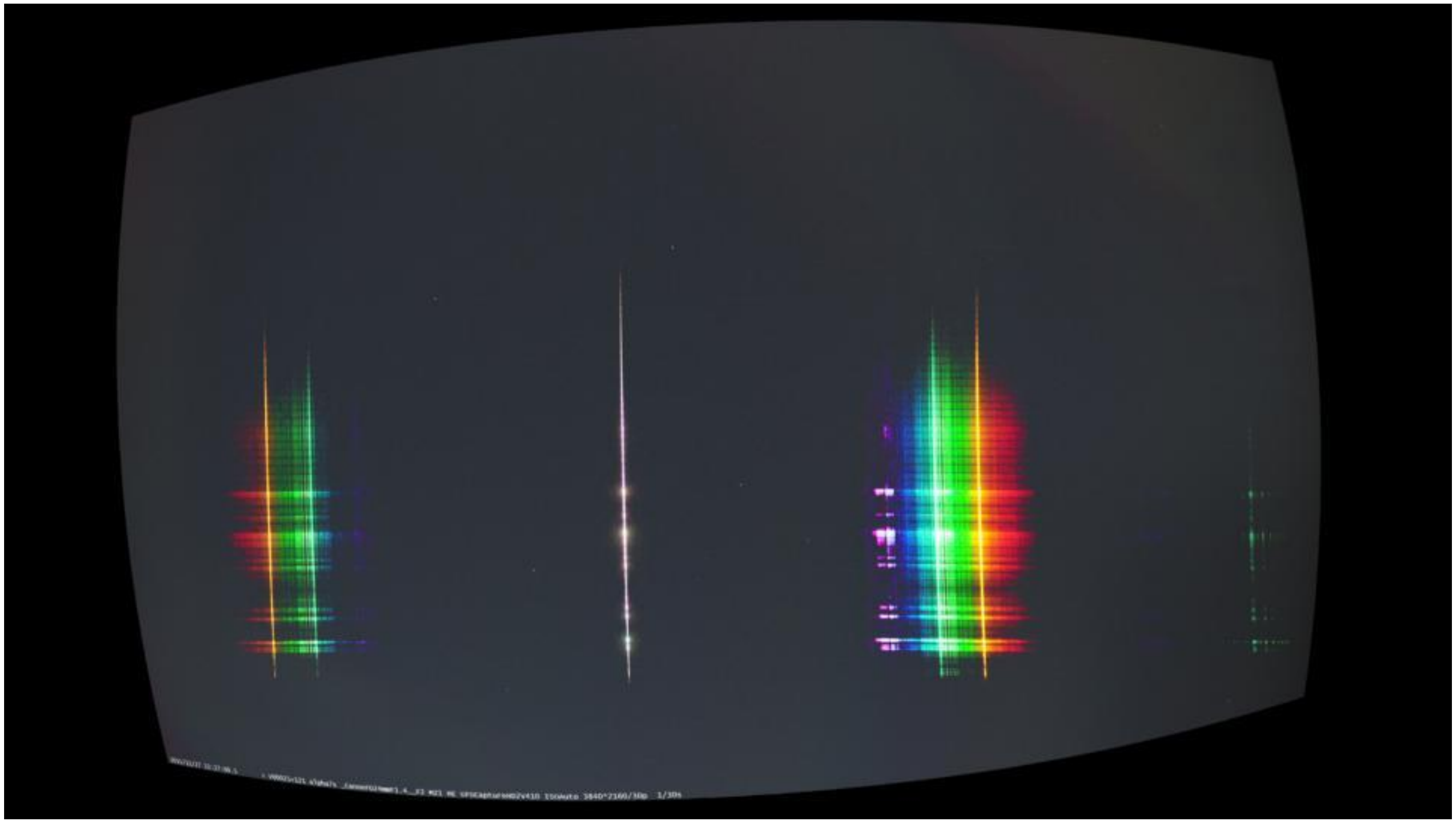
- After background subtraction



Orthographic transformation, original



Orthographic transformation, result



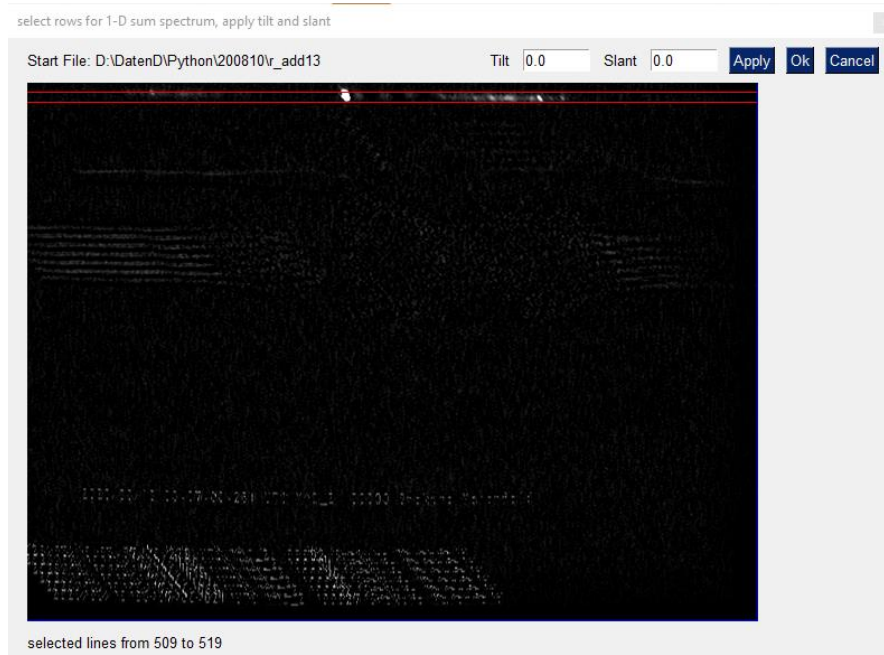
Flat field correction

- Record flat field and subtract offset

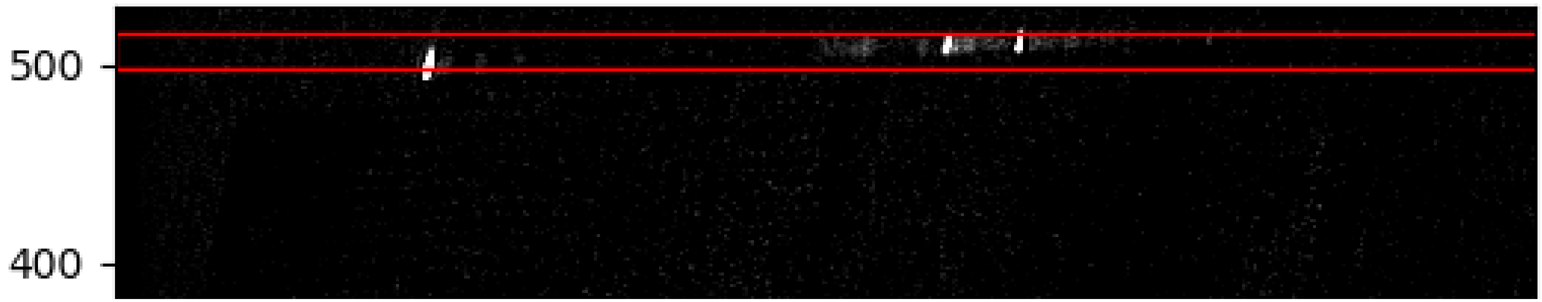
- Flat field after edge exclusion and distortion correction

Registering and stacking spectra

- Select 0 order for registering spectra
- Select range of rows for addition

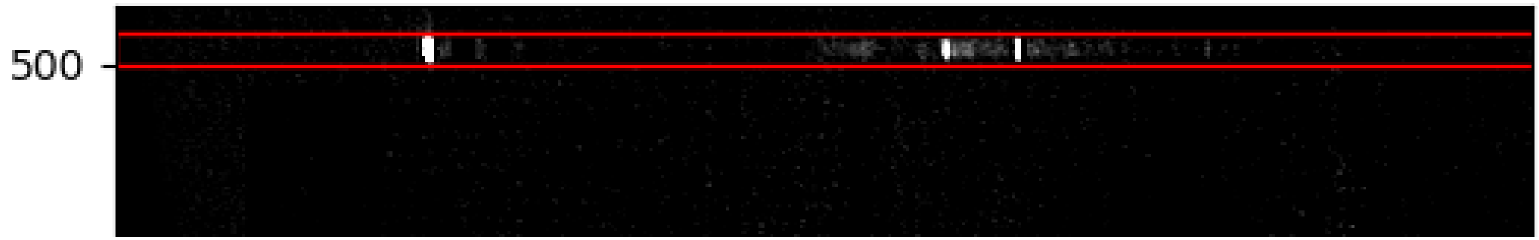


Tilt and slant correction



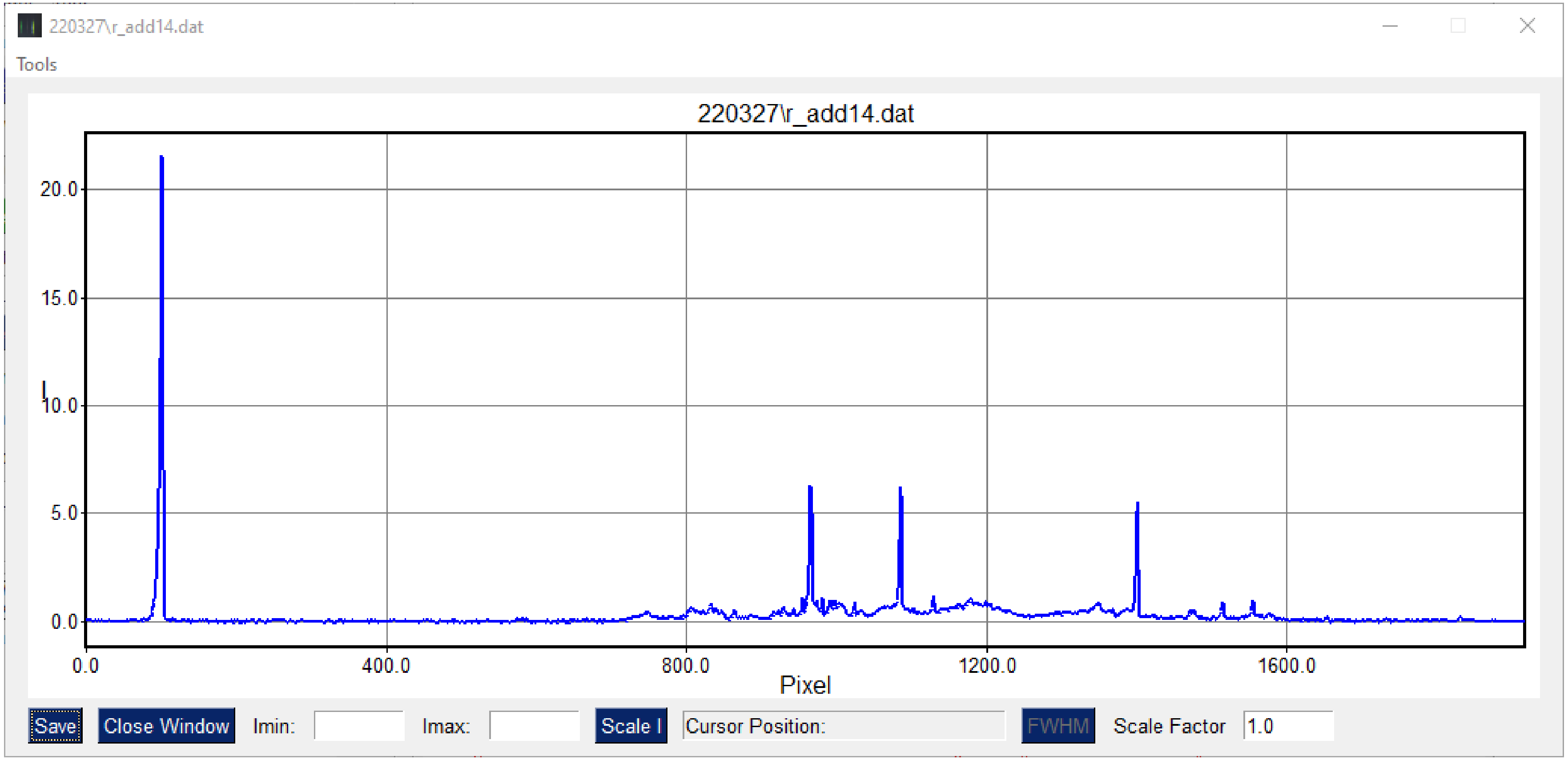
- Tilt correction

- Slant correction



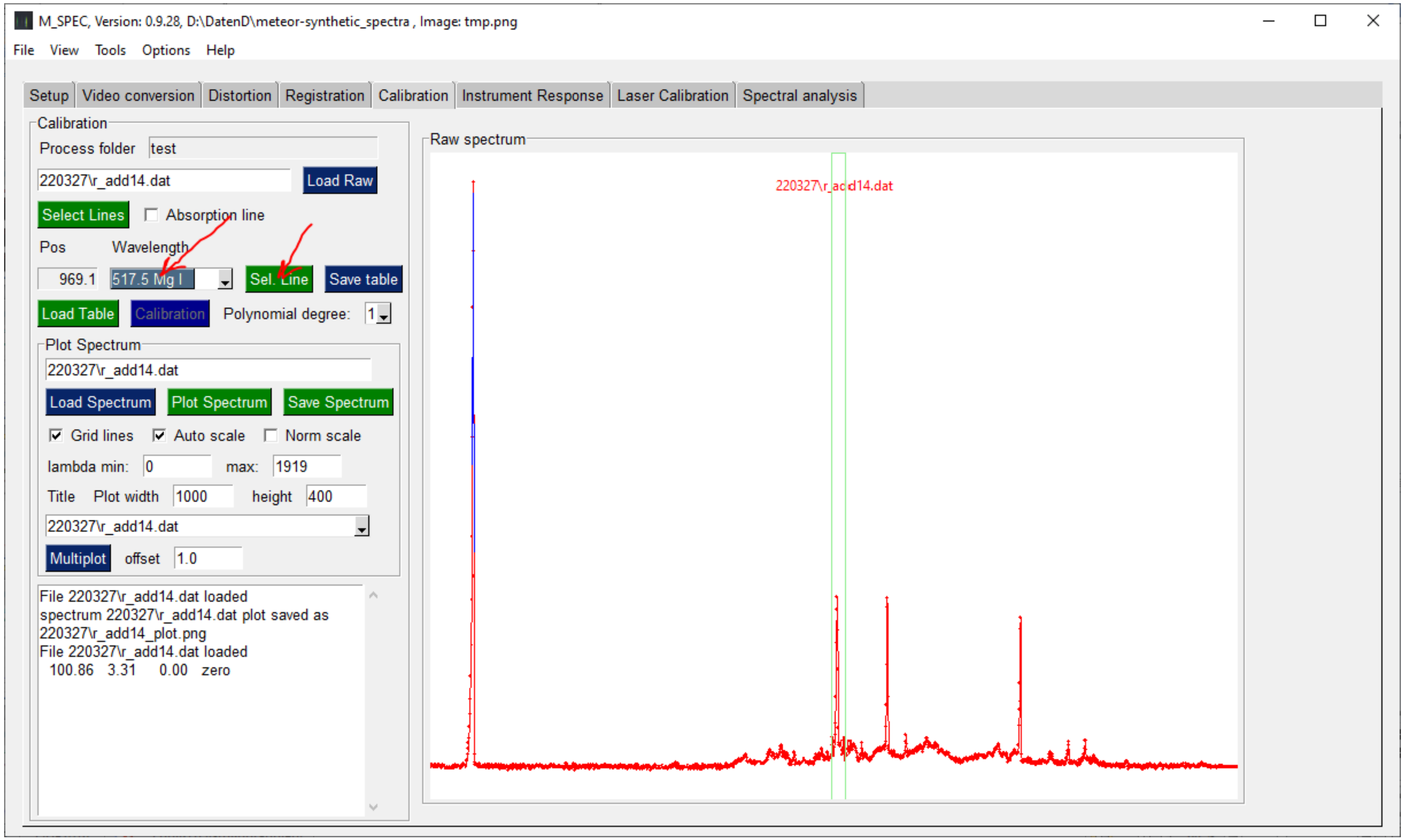
Extract raw spectrum

- Add lines → 1d-spectrum, uncalibrated



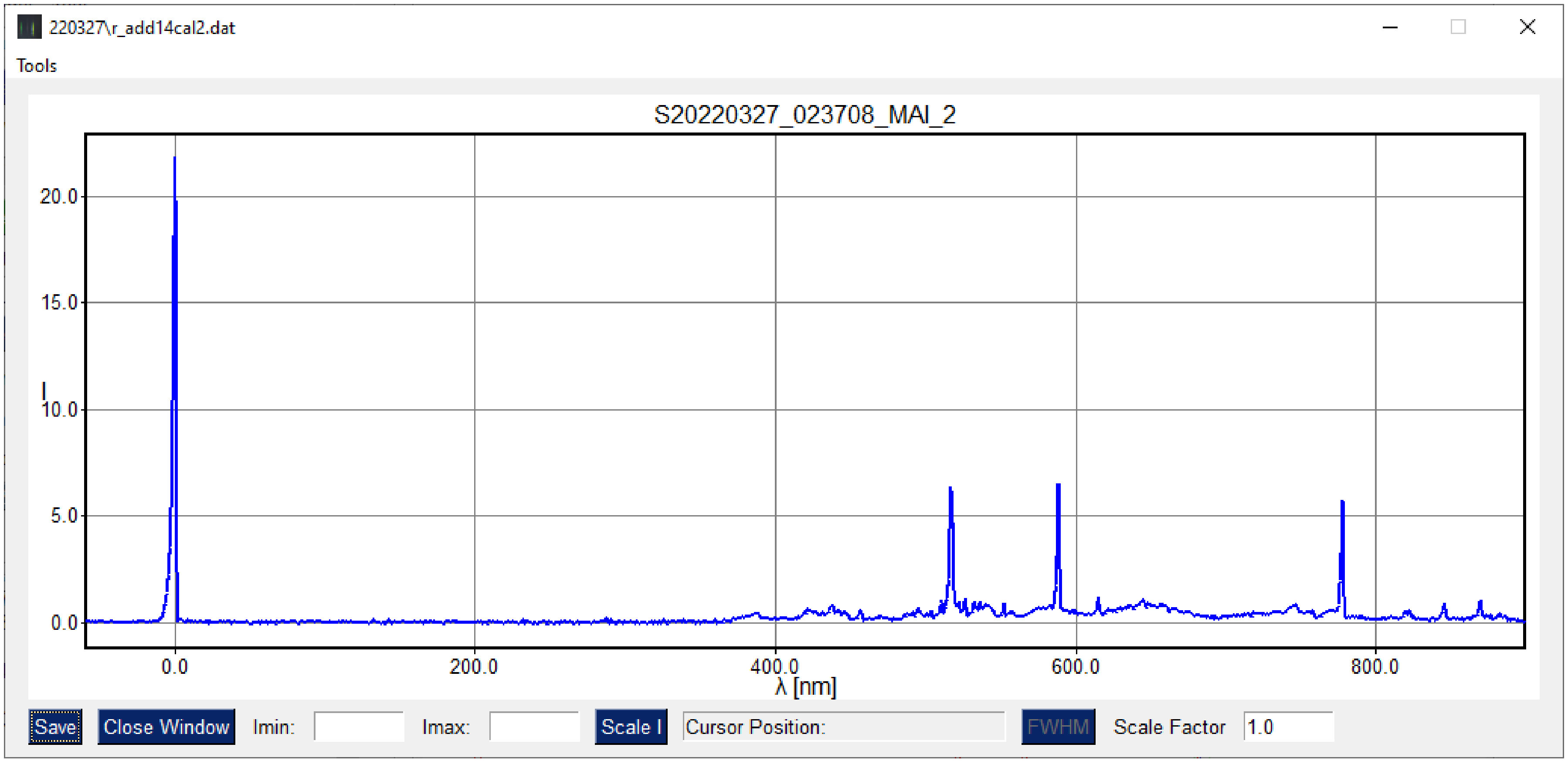
Wavelength calibration

- Select known lines, assign wavelength (0 for zero order)



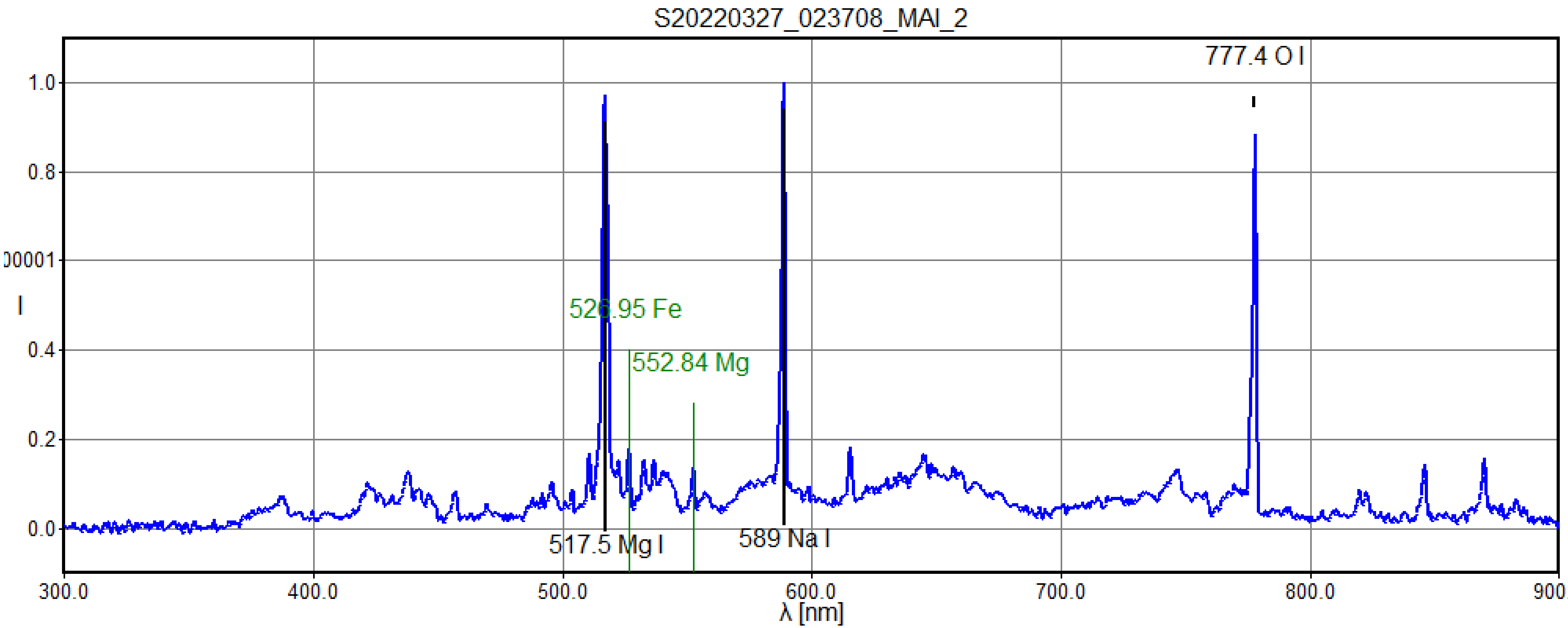
Calibrated spectrum

- After linear or polynomial fit → calibrated spectrum



Plot final spectrum

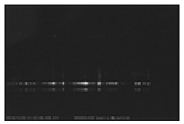
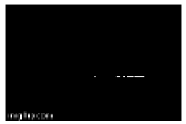
- Select range, set title etc.



Results

- See: http://www.meteorastronomie.ch/ergebnisse_spektroskopie.html or http://www.meteorastronomie.ch/intranet/medienarchiv.php

ERGEBNISSE:

	Bild	Video	Spektrum
			
13. September 2020 Script for analysis	Martin Dubs published his practical script (Python) for the analysis of **meteor spectra**. Additionally, the corresponding description is available too.		
30. Juni 2020 Summary January-June			Analysis
13. April 2020 short and bright	MAI	MAI	Analysis Spectra
31. Dezember 2019 Summary January-December			Analysis

Improvements since last meeting

- Flat field (see above)
- Instrument response, atmospheric extinction
- Improve spectral resolution, HD-Video camera
- Synthetic spectrum

Instrument response (IR)

- Camera sensitivity depends on wavelength
- Recorded signal influenced by grating efficiency, lens transmission
- Also depends on atmospheric transmission, may be included in instrument response
- IR = signal / (incident power/nm), related to quantum efficiency
- Corrected spectrum S = (measured) Intensity / IR

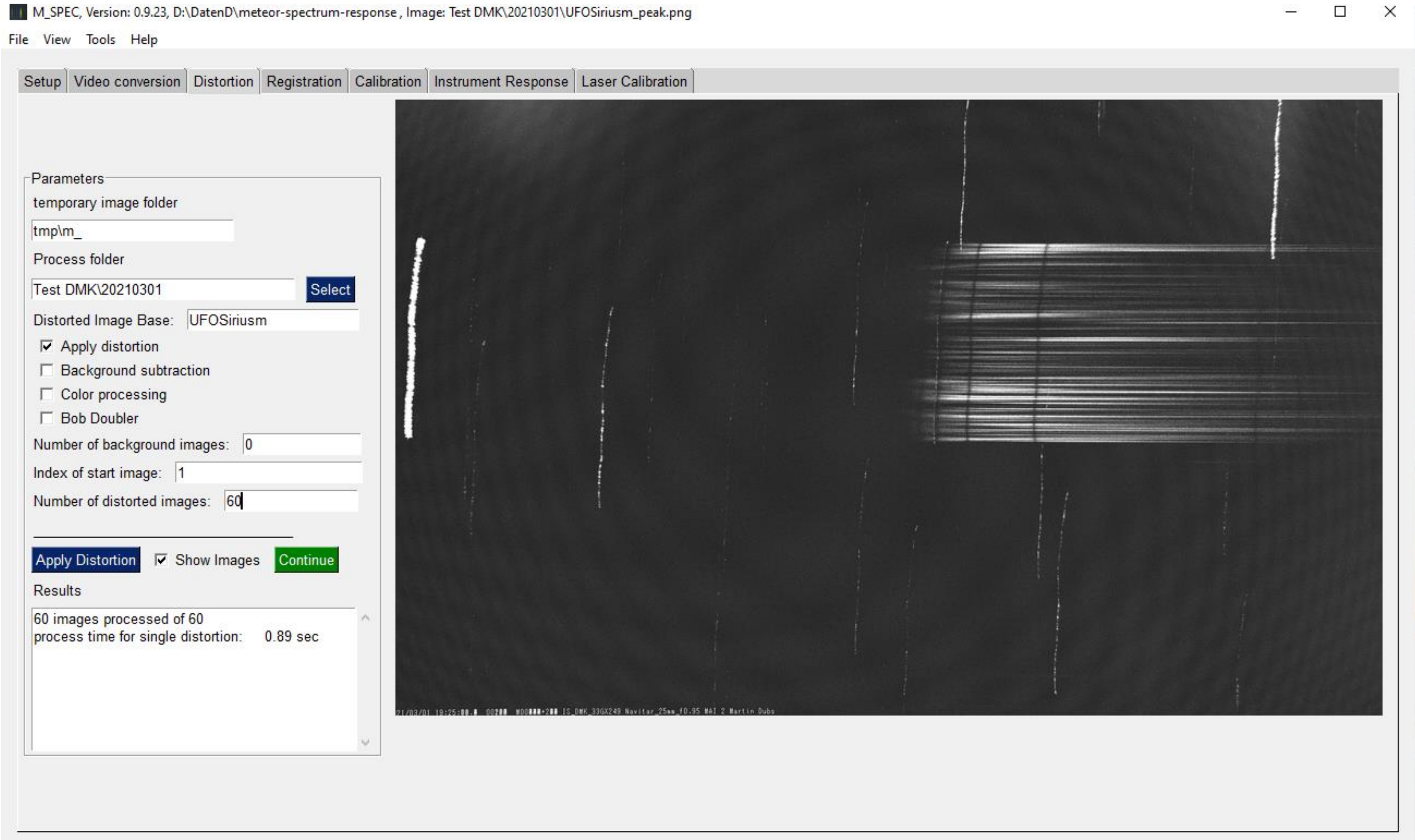
Determination and use of instrument response

- Spectrum of known object (Sirius)
- IR = measured spectrum / reference spectrum (from calib. library)

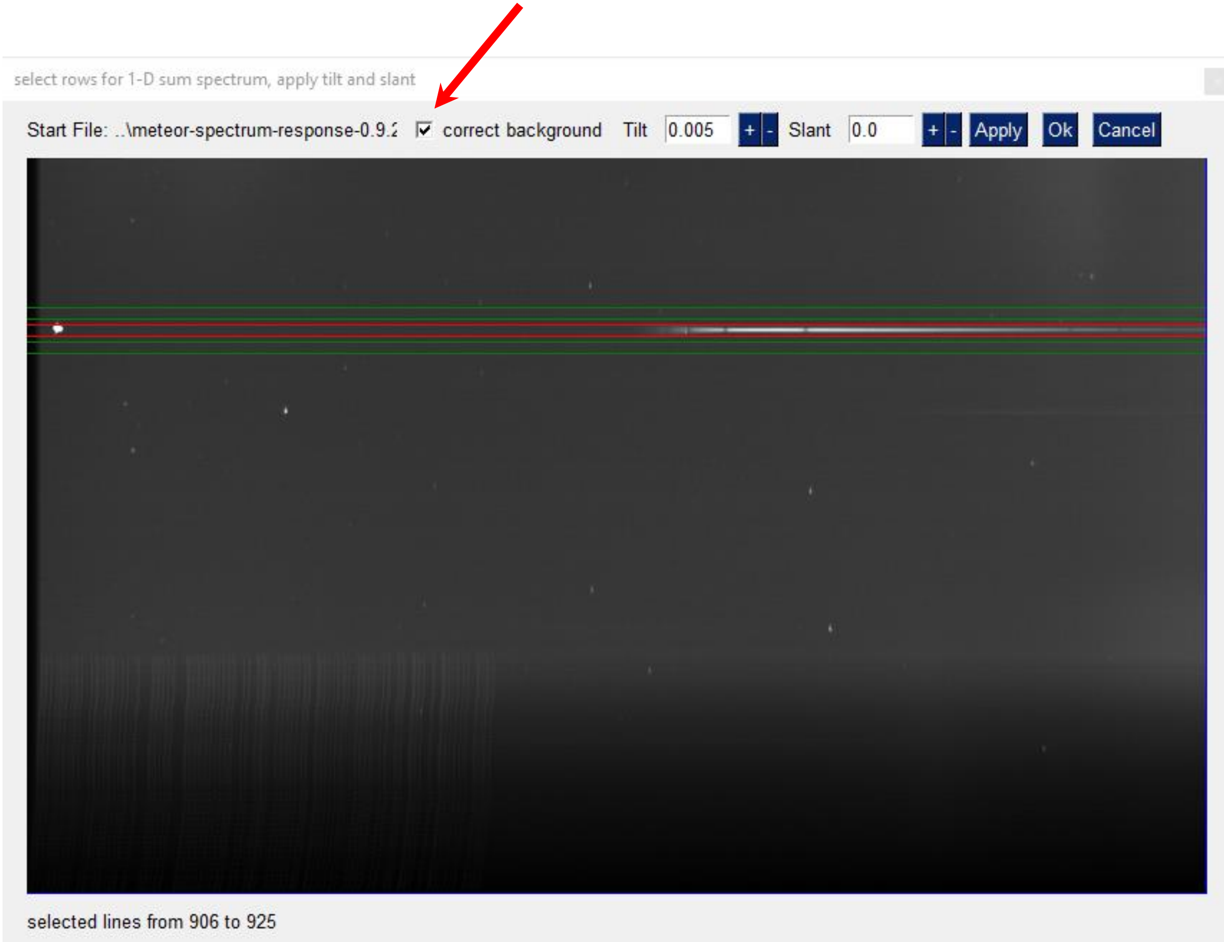
- Meteor spectrum, wavelength calibrated
- Corrected spectrum = meteor spectrum / IR

Reference spectrum

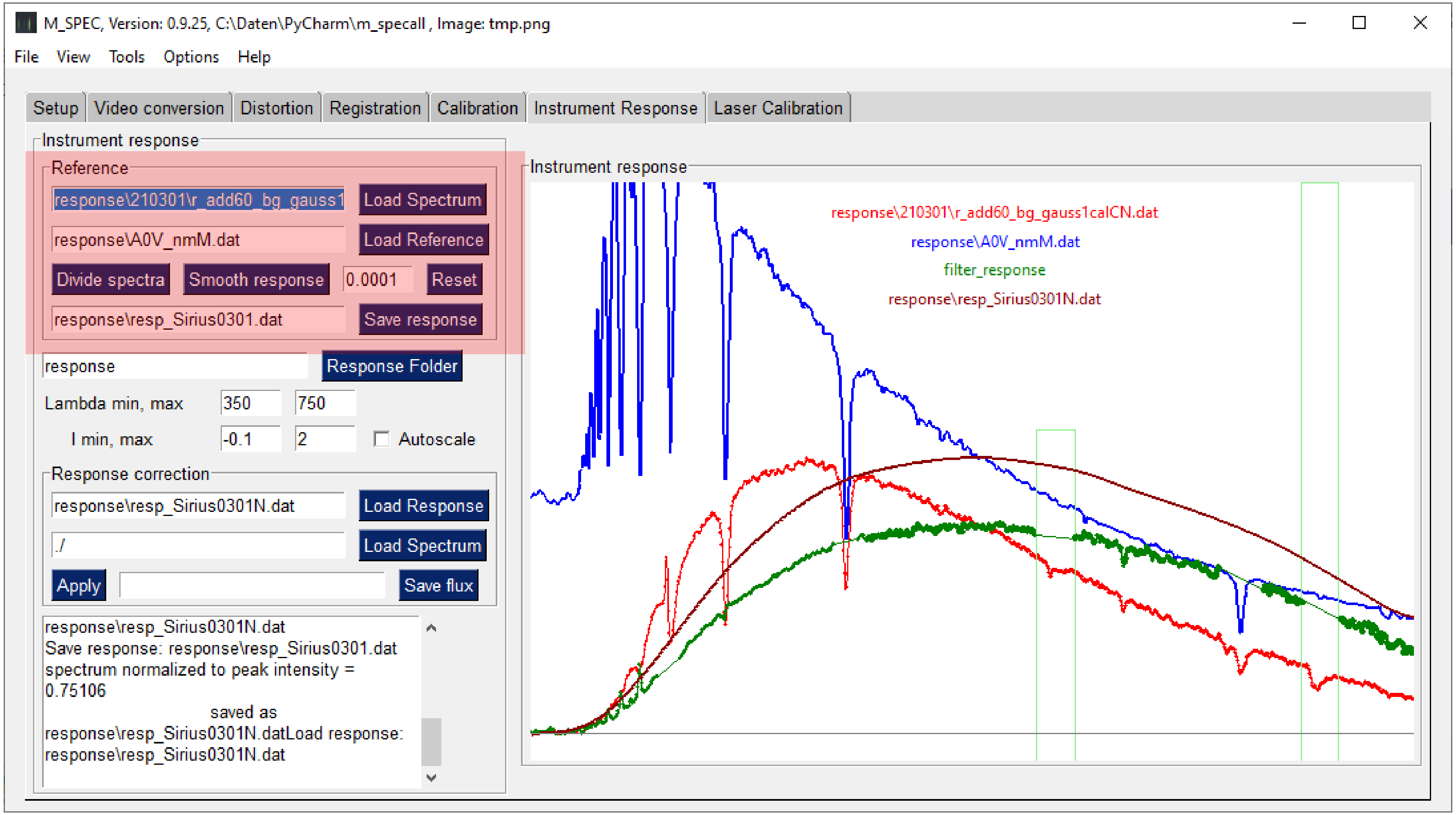
- Sirius, large variation from frame to frame



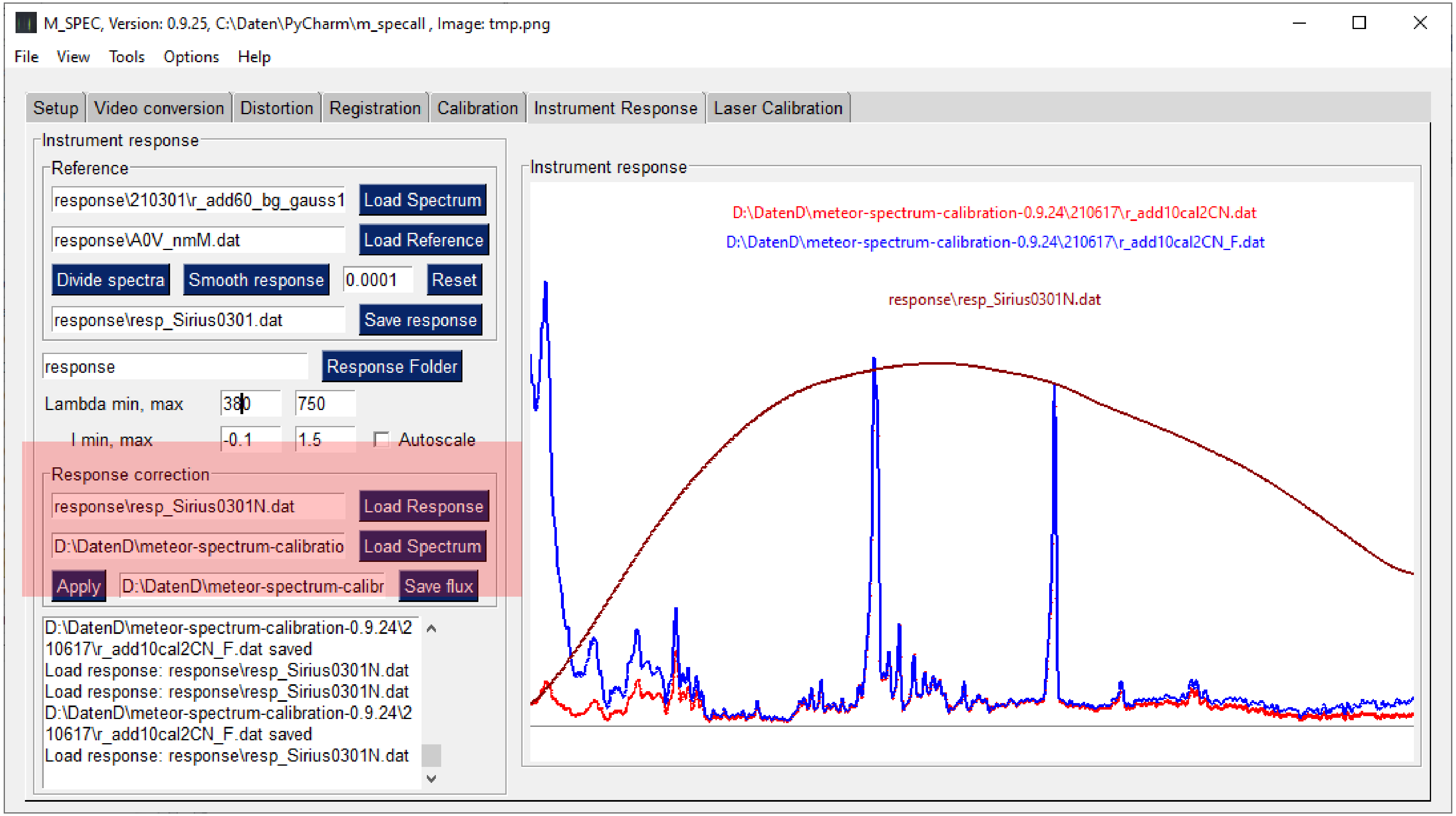
Reference star with background subtraction



Instrument response from reference star

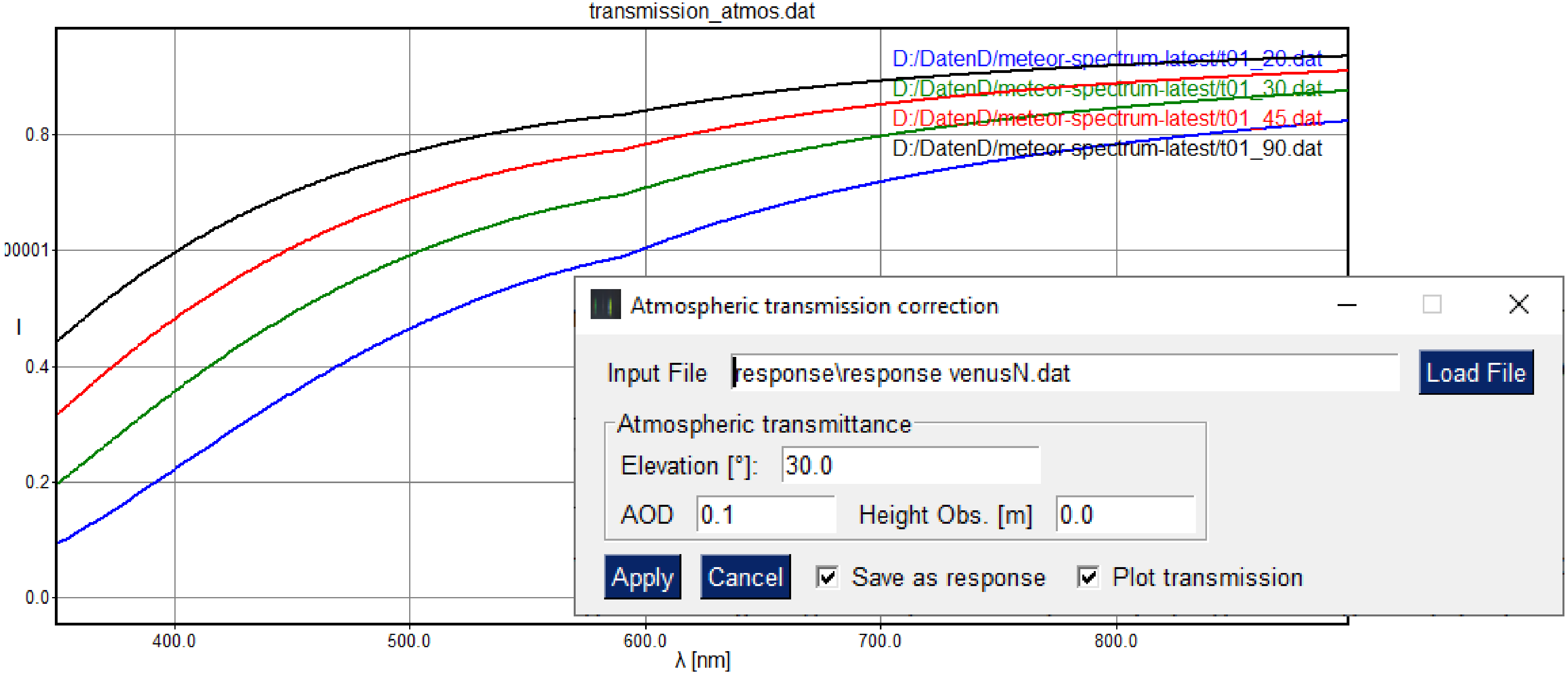


Response correction



Atmospheric correction

- Depends on air quality and zenith distance, details see: https://meteorspectroscopy.org/2021/09/26/atmospheric-extinction-python-processing/



Characteristic meteor spectra

- Catalogue of meteor spectra: V. Vojacek et. Al. http://adsabs.harvard.edu/abs/2015A%26A...580A..67V

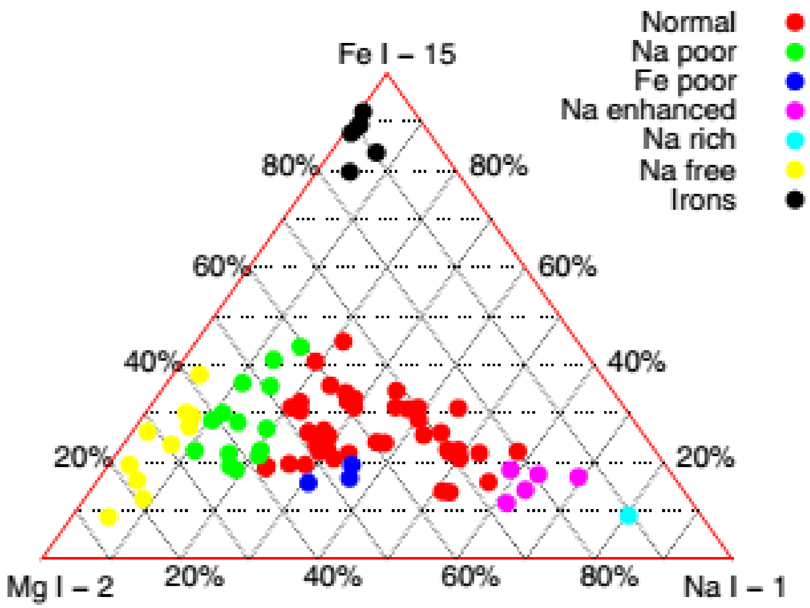


Fig. 8. Classification of meteor spectra. The ternary graph of the Mg I (2), Na I (1), and Fe I (15) multiplet relative intensities. Every group of meteoroids is represented with a different symbol.

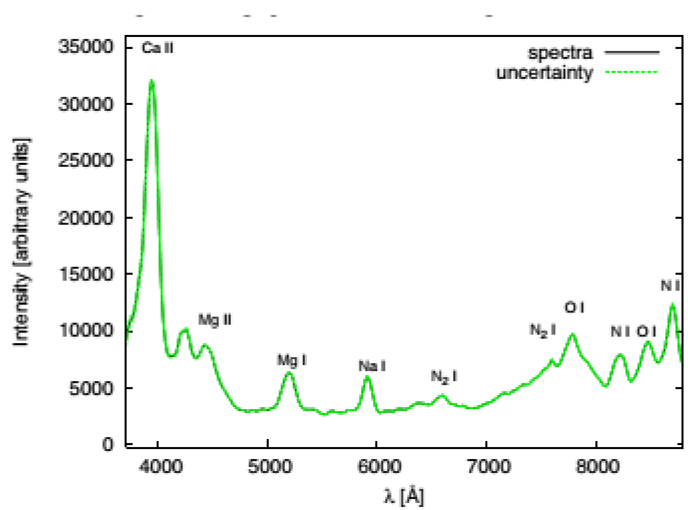


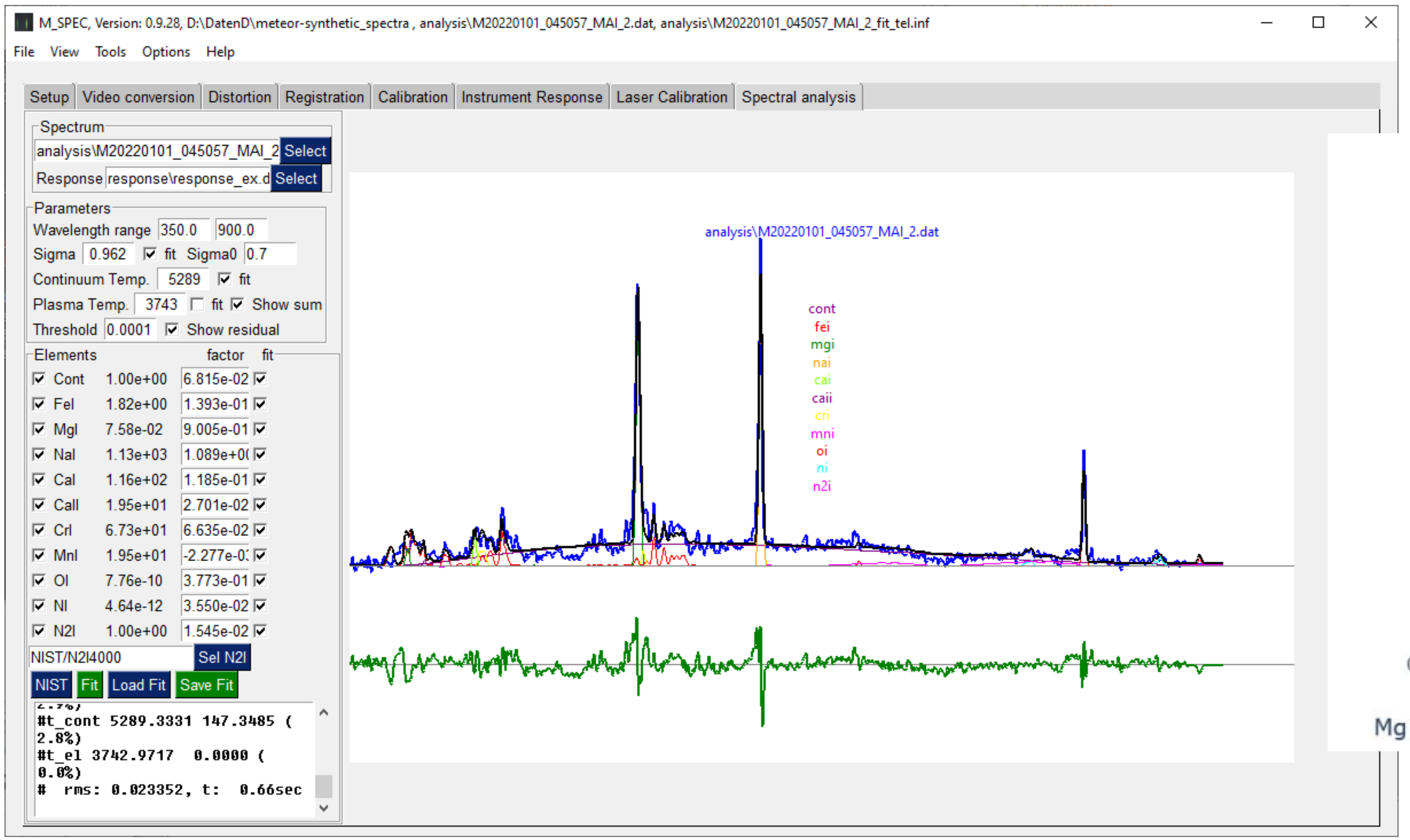
Fig. 5. Spectrum SX1837 of a bright Perseid. The meteor had a maximum brightness of −9.2 mag. Because the spectra were oversaturated on the video frames around the brightness maximum, one frame of the sequence was chosen. The brightness of the meteor in this frame was −7.5 mag.

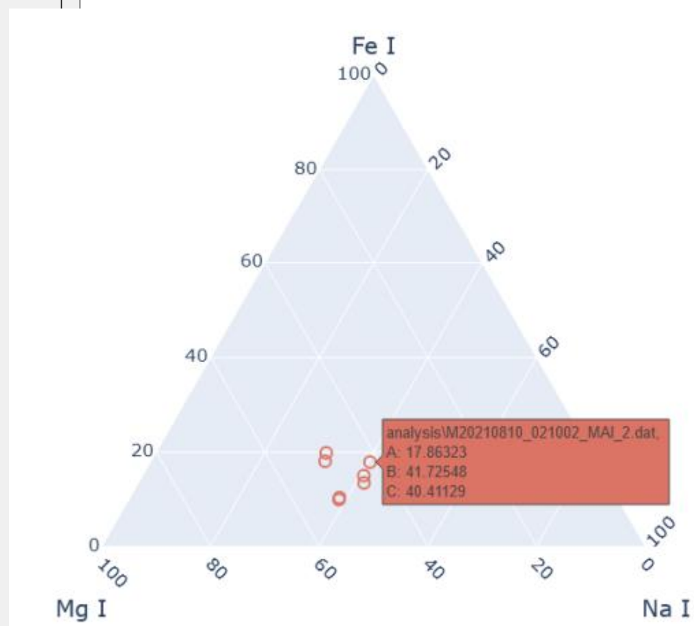
Synthetic meteor spectra

- Calculation of spectrum for plasma temperature, element abundance
- Inclusion of Planck continuum and molecular nitrogen band
- Fit of linewidth, abundance, plasma and continuum temperature
- Instrument response function applied to synthetic spectrum

Synthetic meteor spectra

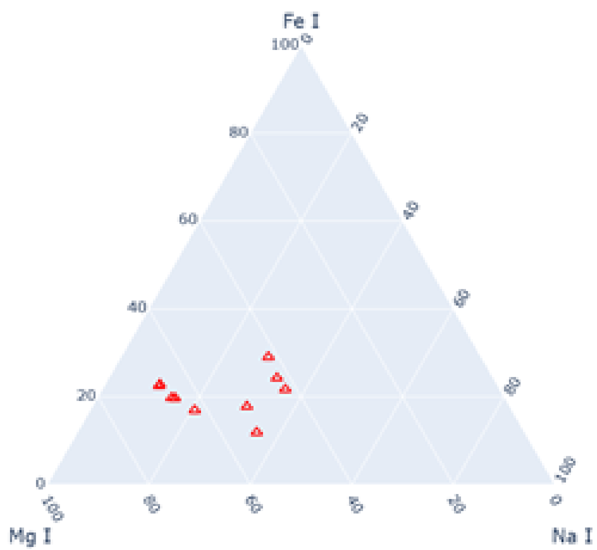
- Calculation of spectrum for plasma temperature, element abundance
- After fit of linewidth, abundance, plasma and continuum temperature:





Synthetic spectra applied to Geminids

- My results 2021 compare with Abe, Maeda: https://www.researchgate.net/publication/344481278_Sodium_variation_in_Geminid_meteoroids_from_3200_Phaethon



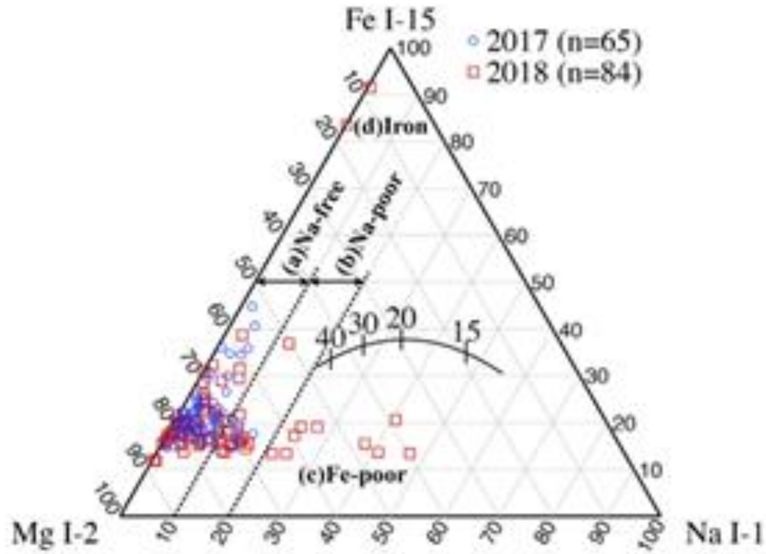


Fig. 5. Ternary plot for Na I (1), Mg I (2), and Fe I (15) multiplets in 149 Geminid meteor spectra. The 2017, 2018 Geminids are indicated by blue circles and red squares, respectively. The solid curve is a theoretical reference line for the chondritic (CI) meteor ablation. The velocity (in km s^{-1}) are marked with numbers. The excitation temperature changes along this theoretical line. For speeds larger than 40 km s^{-1}, the line ratios should not change substantially. The initial velocity of the Geminids is about 35 km s^{-1}. Four classifications, Na-free, Na-poor, Fe-poor and Iron were shown. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Python meteor spectrum processing

- Python: https://www.python.org/
  (https://www.anaconda.com/download/#windows)
- Spectrum processing manual:
  https://github.com/meteorspectroscopy/meteor-spectrum-calibration/blob/master/doc/M_spec%20Python%20manual.pdf
  summary:
  https://meteorspectroscopy.org/2020/03/27/meteor-spectra-analysis-new-version/
- scripts and demo spectra, latest version:
  https://github.com/meteorspectroscopy/meteor-spectrum-calibration

Conclusion

- Grating mounted perpendicular to camera axis
- Orthographic image transformation gives linear spectra!
- Python script gives fast spectrum analysis

Acknowledgment

- FMA (division of Swiss (Amateur) Astronomical Society) for data, discussion
- Koji Maeda (HD color spectra)
- Giovanni Leidi for inspiration to use Python

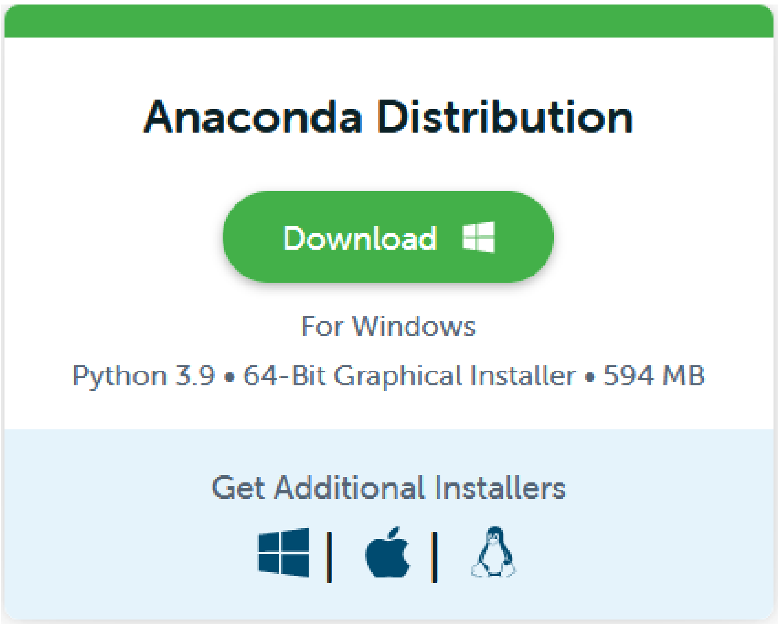
Thank you!

Testrun m_spec.py

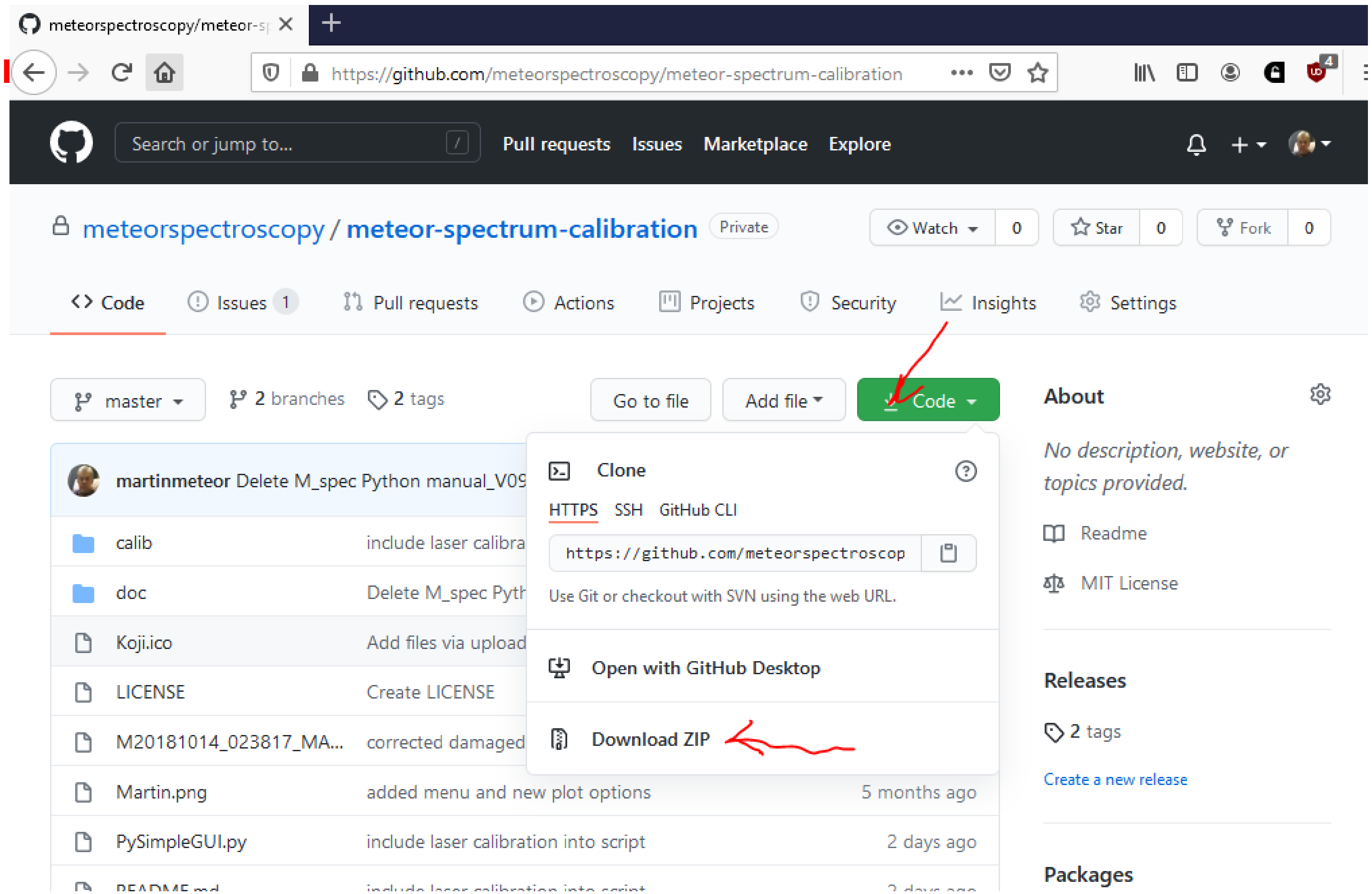
- Install Python from Anaconda
- Download meteor-spectrum-calibration from Github
- Edit Anaconda prompt (set working directory)
- Run m_spec.py with: python m_spec.py
  - m_set.ini for calibration
  - Run calibration
  - Run meteor spectrum example
- Results, logfile

Download Anaconda

- https://www.anaconda.com/download/
- Select the 32 or 64 bit version, depending on your computer.
- Python 3.6 – 3.9 have been tested with my script



Download from Github



Install Anaconda, run script in shell

- Copy Anaconda prompt to Desktop (move to start, copy from there)
- Adjust working directory
- Run with: python m_spec.py
- Alternative use Spyder
  before I used Pyzo