First results from digital fireball spectra

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Introduction to meteor spectra - Temperature components

- The observed spectrum is a superposition two spectra
- Main spectrum (meteor 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) - $\sim$ **10000 K**
  - Fe II, Ca II, Mg II, Ti II, Si II
- Second spectrum present only in fast meteors

(Spectral) Digital Autonomous Fireball Observatory

European Fireball Network station.

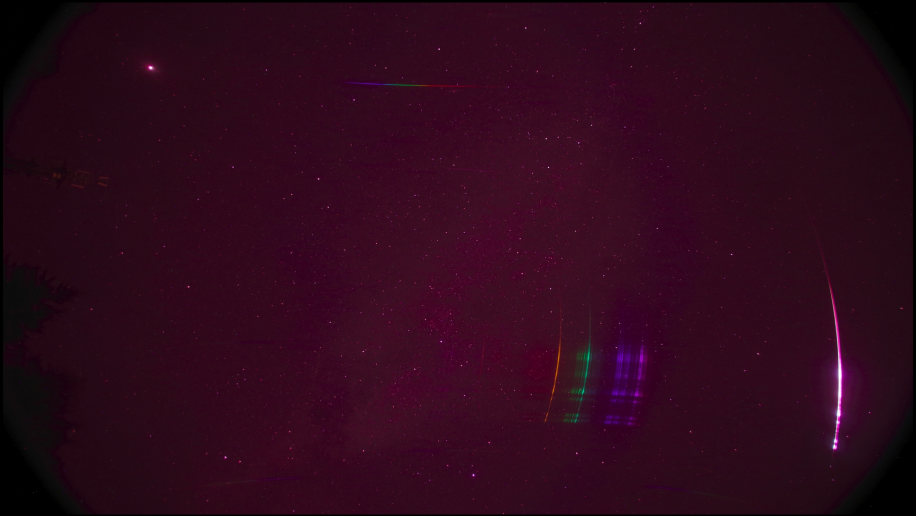
Equipment: Digital Canon EOS 6D cameras

- focal length of 15mm
- 1:2.8 focal ratio
- 35.8 x 23.9 mm sensor size
- resolution 5472 x 3648 px
- **1000 grooves/mm** plastic holographic grating

- limiting magnitude $\sim$ -7
- exposure time of 30s
- **dispersion** 4 Å/pixel
- **removed IR-cut filter**
- spectral range 3800 - 9000 Å
- (FOV $\sim$ 100° x 140°) x 2

Example meteor: Jupiter Family sporadic, v = 22 km/s

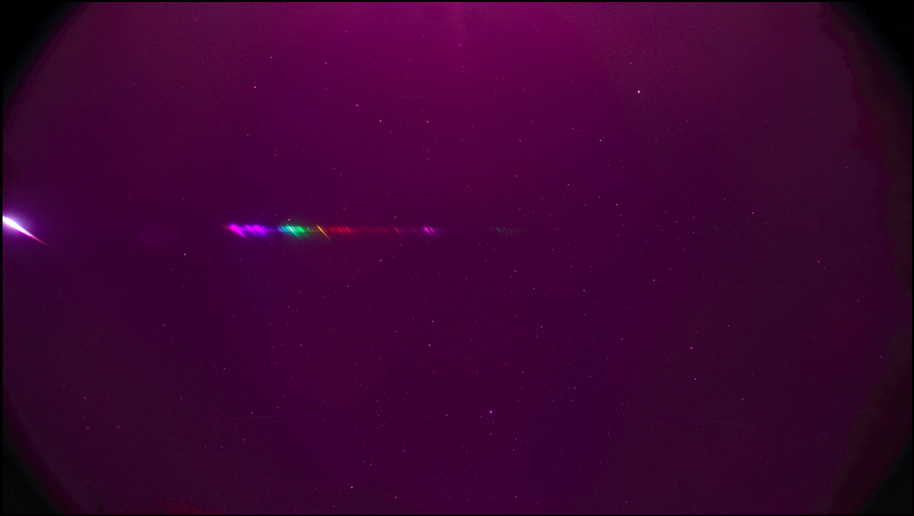
Example meteor: Taurid, v = 34 km/s



Example meteor: Quadrantid, v = 42 km/s

Example meteor: Quadrantid, v = 42 km/s

Example meteor: Lyrid, $v = 48$ km/s



Example meteor: Halley-type sporadic, v = 50 km/s

Example meteor: Perseid, v = 60 km/s

Example meteor: Leonid, v = 72 km/s

Obtaining the spectrum from the image

- RAW (cr2) images are converted into grayscale linear-gamma 16-bit TIFF images using an official CANON software.
- Astrometry, photometry and the spectral acquisition are all performed in the FishScan software.
- A wavelength/intensity plot is created by summing up total pixel intensities along the path of the meteor spectrum segment.

Calibration

- Performed in self-written Python code
- Wavelength calibration
- Intensity calibration
  - Flat-field (vignetting)
  - Spectral sensitivity (camera sensor)
  - Atmospheric extinction
- Instrumental response (profile shapes)
- Calibration is reliable for wavelengths in the 4000 - 6000 (7000) Å range.

Paper published in Experimental astronomy

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Improvements in digital meteor spectra reduction

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Physical characterisation of a spectrum

- TDE is assumed and implementation follows the procedure from Borovička 1993.
- Atomic data required for the calculation was obtained from the NIST database, using a python-automated web-browser:
  - atomic masses of the elements
  - ionisation energies
  - partition functions
  - oscillator strengths

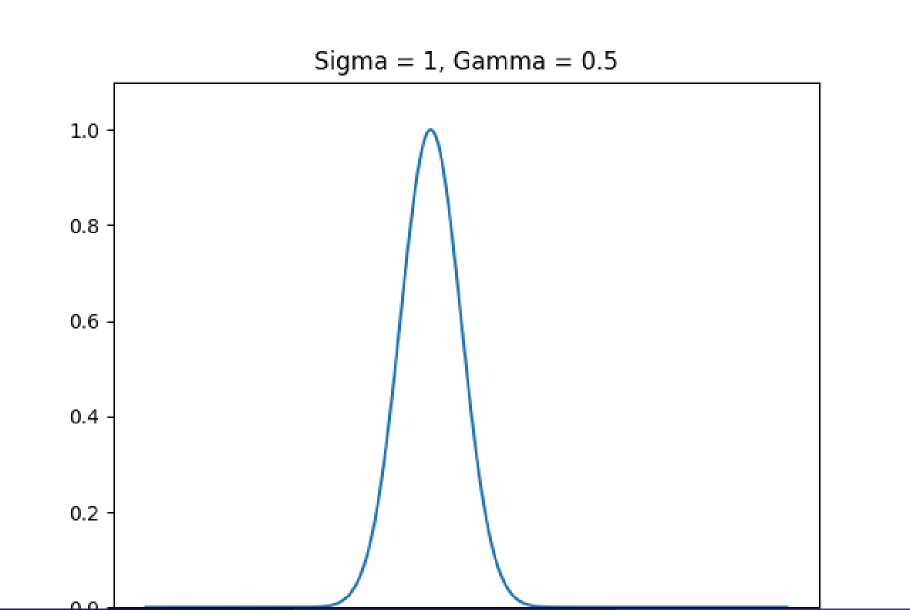
Physical characterisation of a spectrum

- We want to know the theoretical intensities of the spectral lines at given conditions.
- All spectral lines have some physical width, so assuming a Voigt line profile $H(a, u)$, the total intensity of the spectral line is calculated.

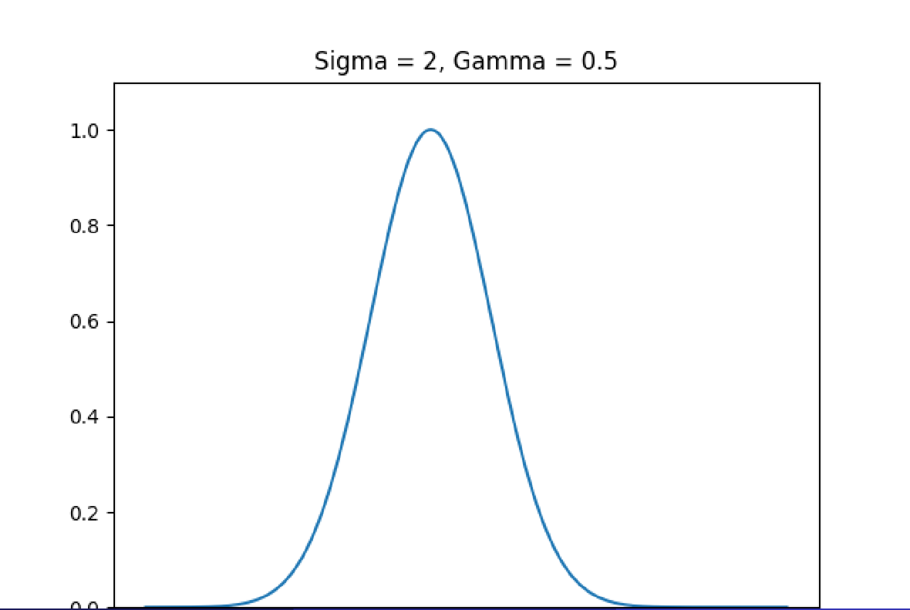
$$I_{total} = 2PB_{\nu}\Delta\nu_D \int_0^{\infty} \left(1 - e^{-N\sigma H(a,u)}\right) du$$

- The goal is to create a synthetic spectrum with the same profile shapes as the observed ones.
- To do that, we first find the dependence of the profile shapes on wavelength.

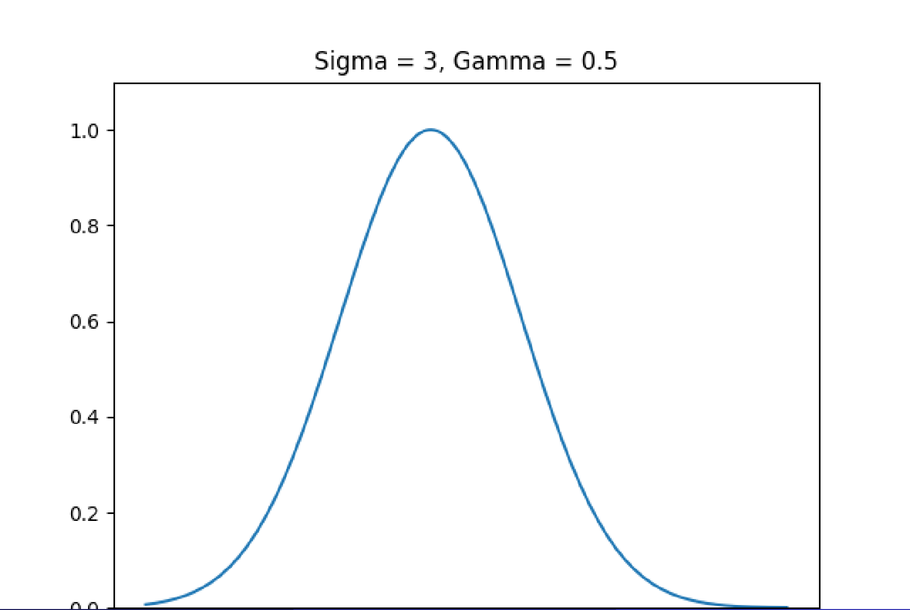
Voigt profile: Gaussian factor



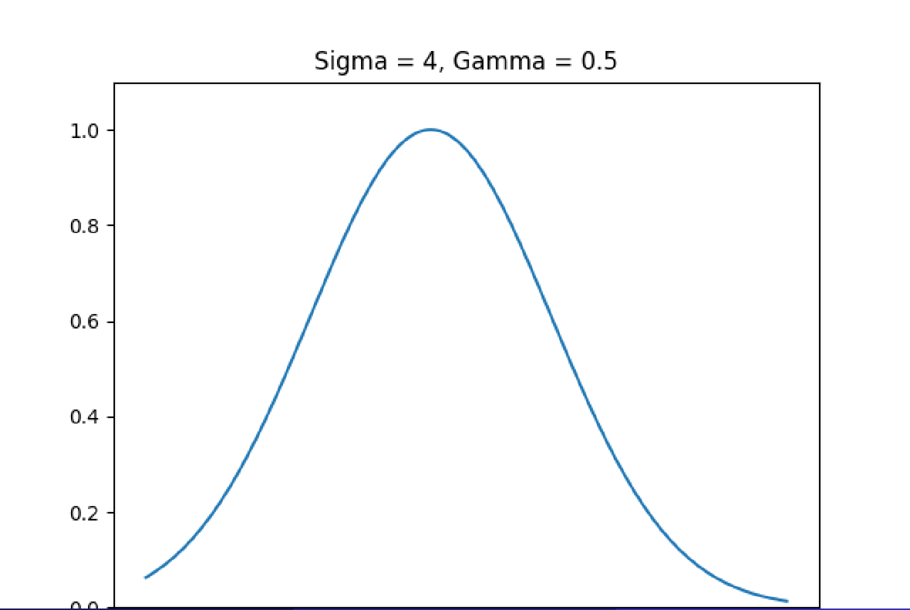
Voigt profile: Gaussian factor



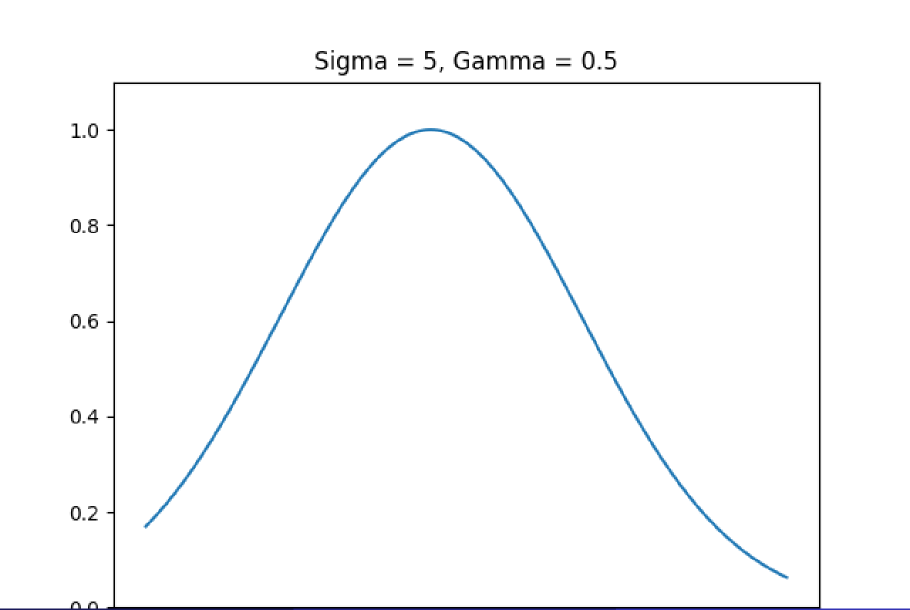
Voigt profile: Gaussian factor



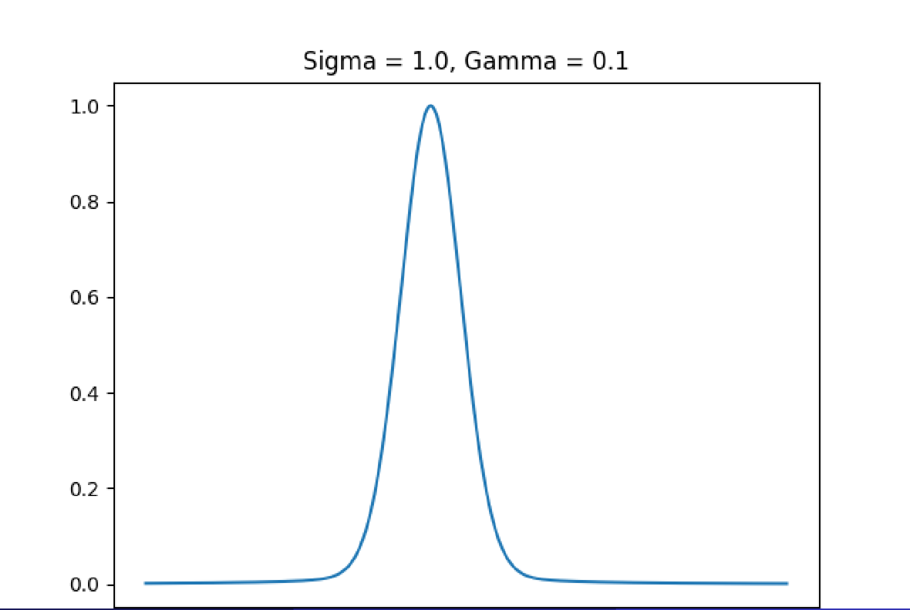
Voigt profile: Gaussian factor



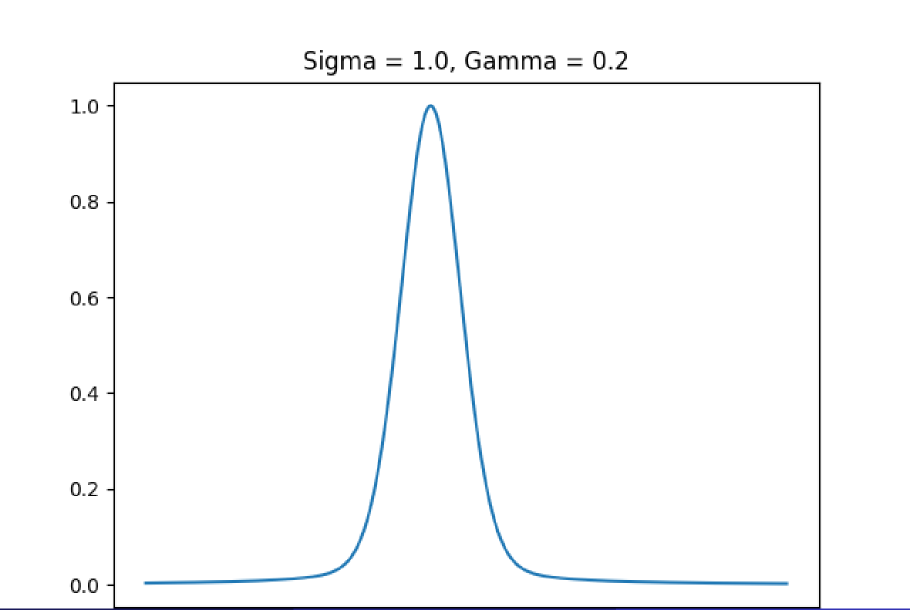
Voigt profile: Gaussian factor



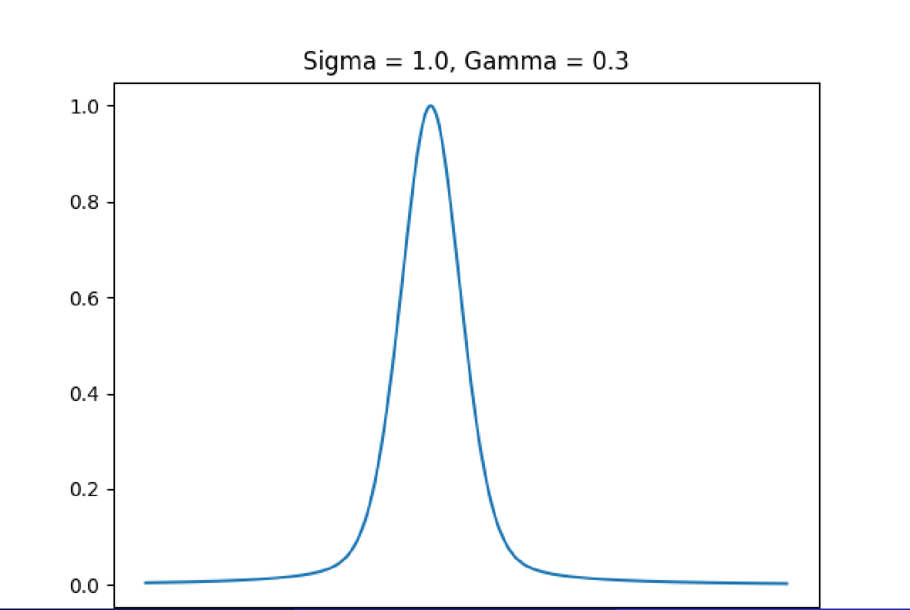
Voigt profile: Lorentz factor



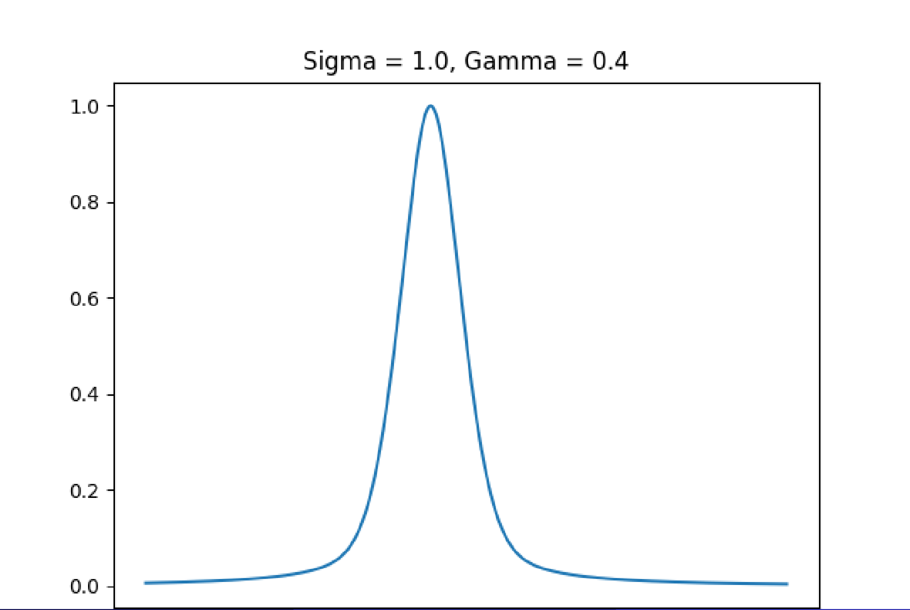
Voigt profile: Lorentz factor



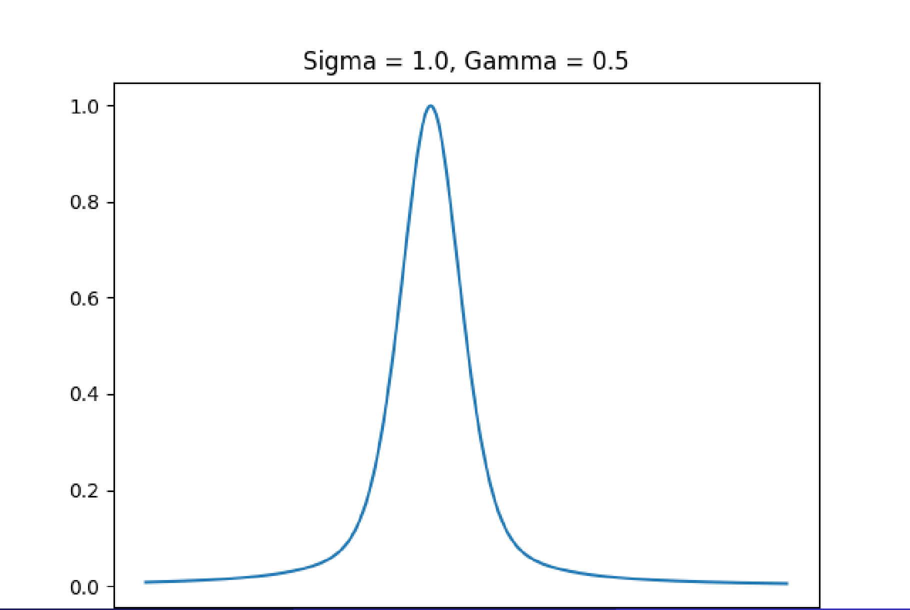
Voigt profile: Lorentz factor



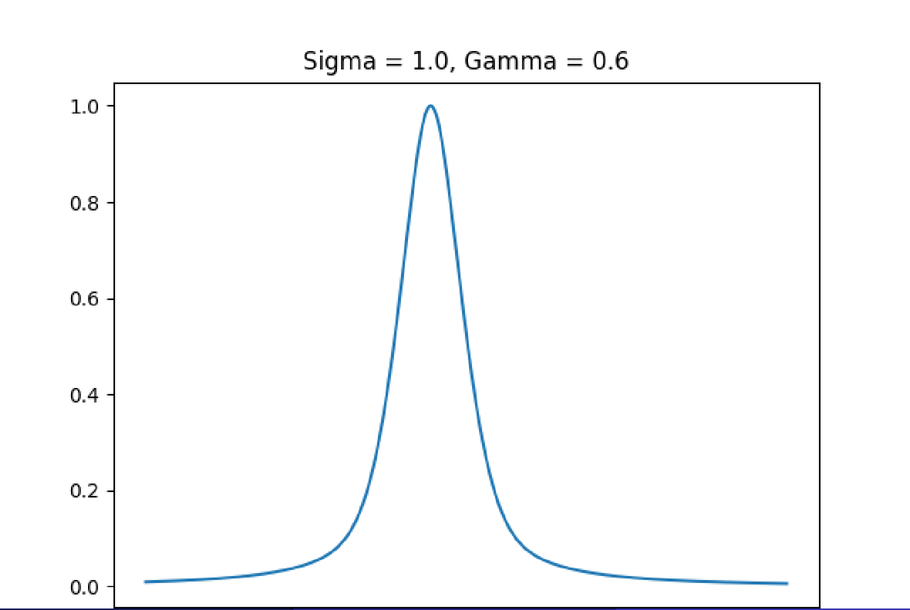
Voigt profile: Lorentz factor



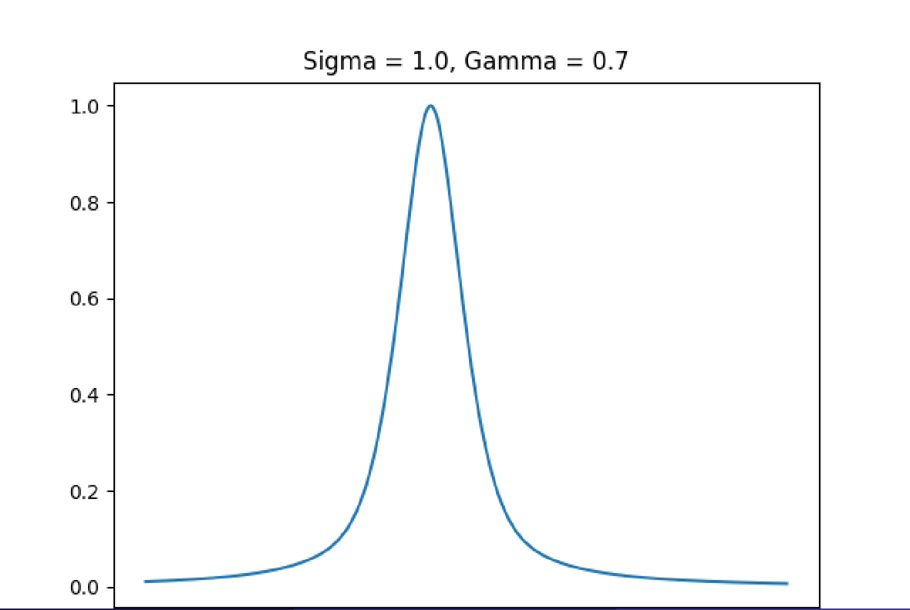
Voigt profile: Lorentz factor



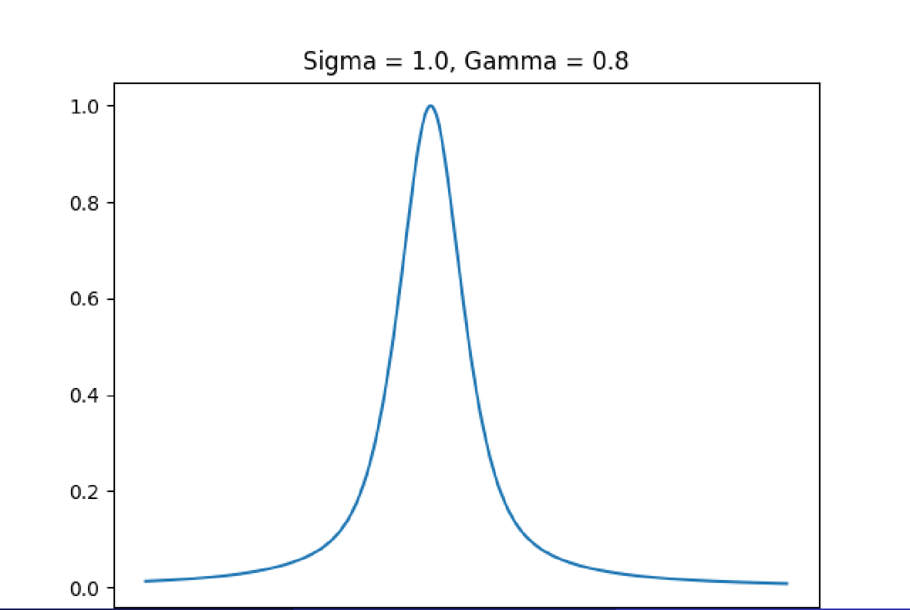
Voigt profile: Lorentz factor



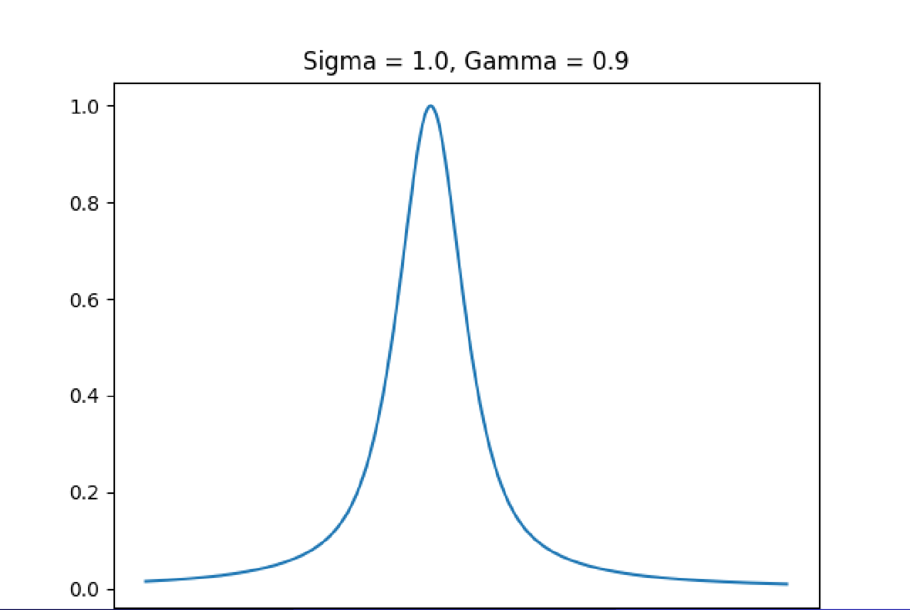
Voigt profile: Lorentz factor



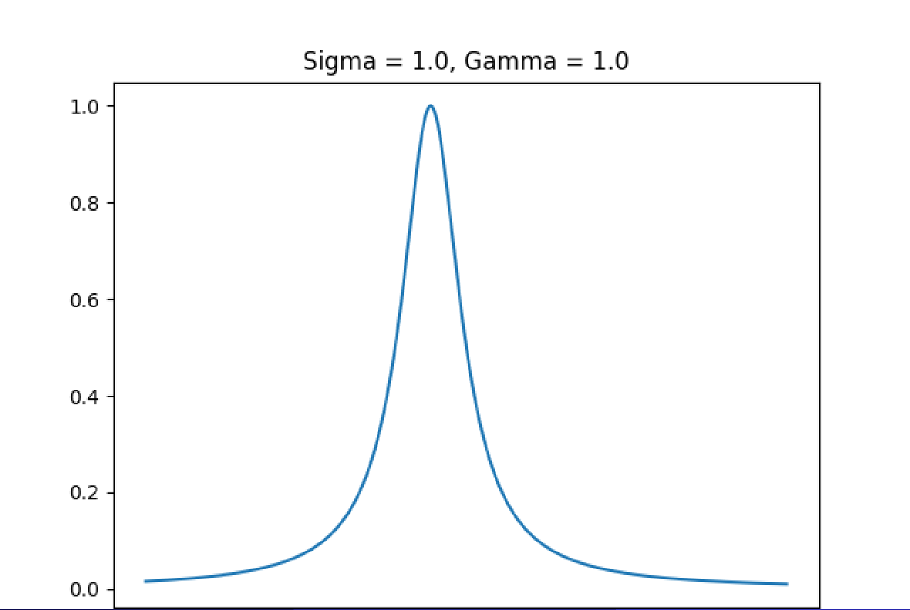
Voigt profile: Lorentz factor



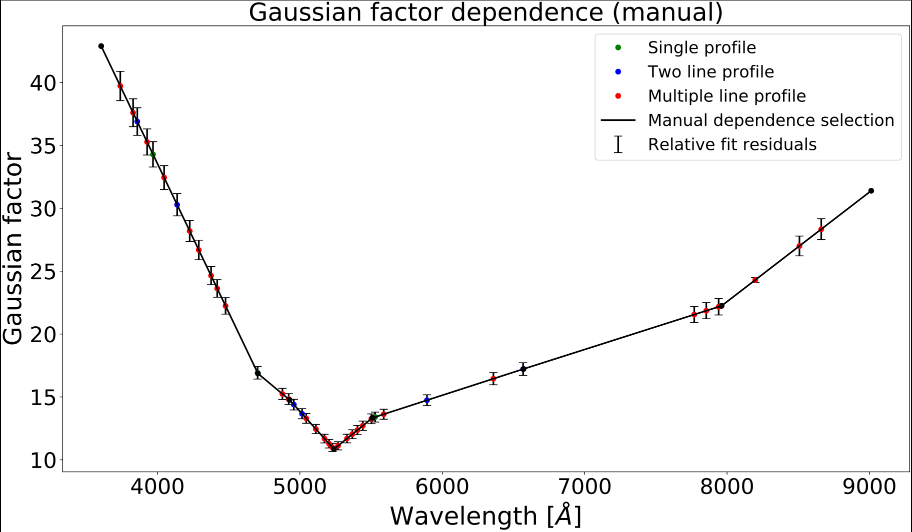
Voigt profile: Lorentz factor



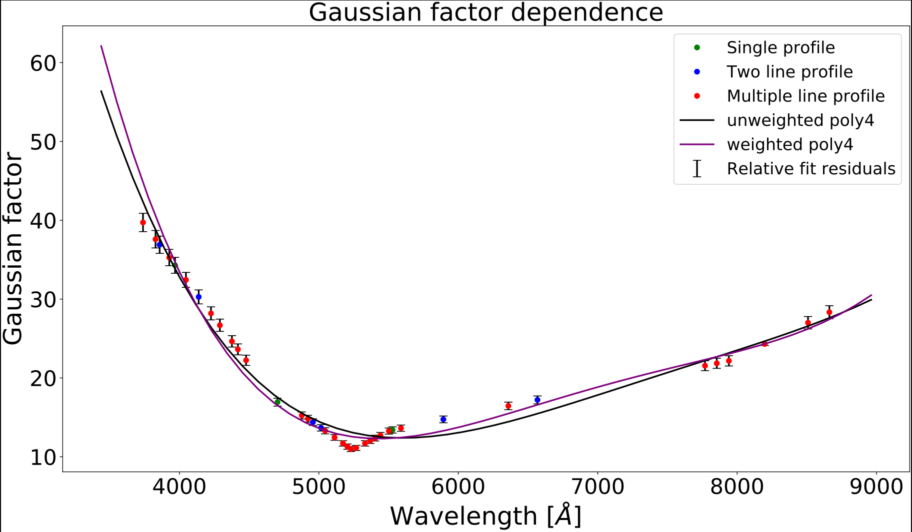
Voigt profile: Lorentz factor



Instrumental response (manual)



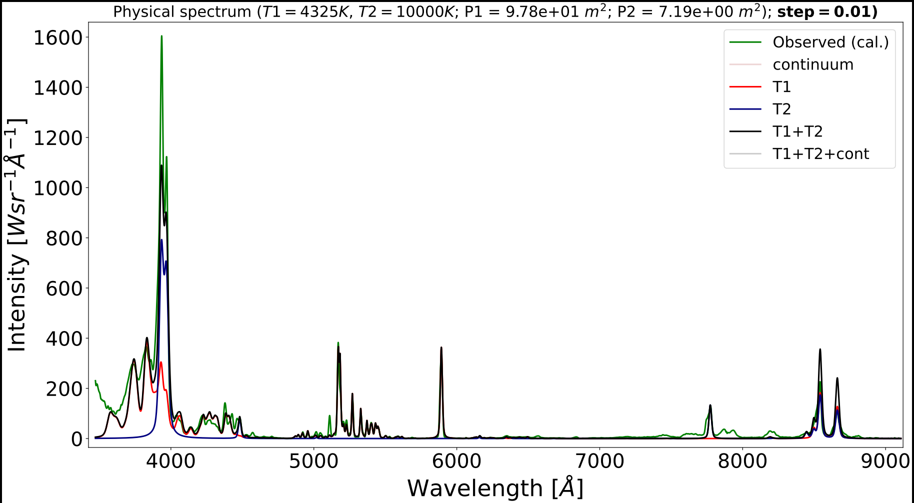
Instrumental response (polynomial)



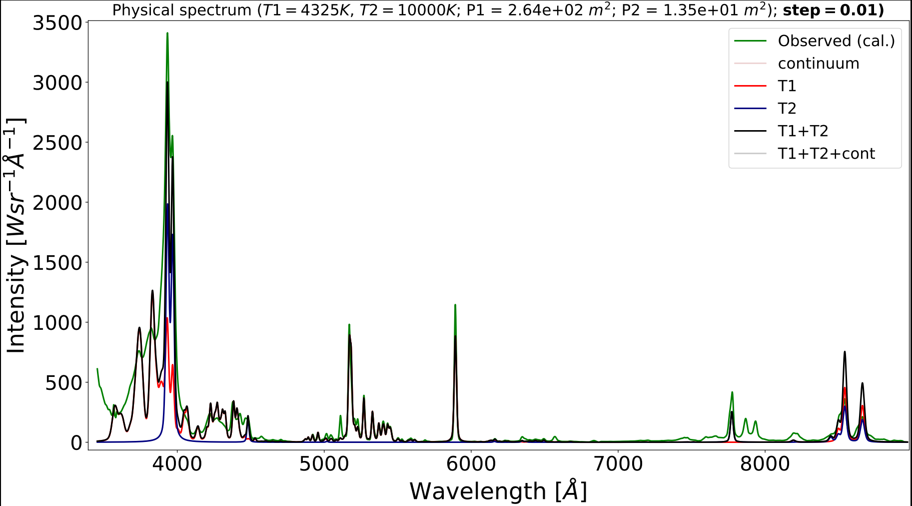
SP20180705_2312_214N-1

SP20180705_2312_214E-0

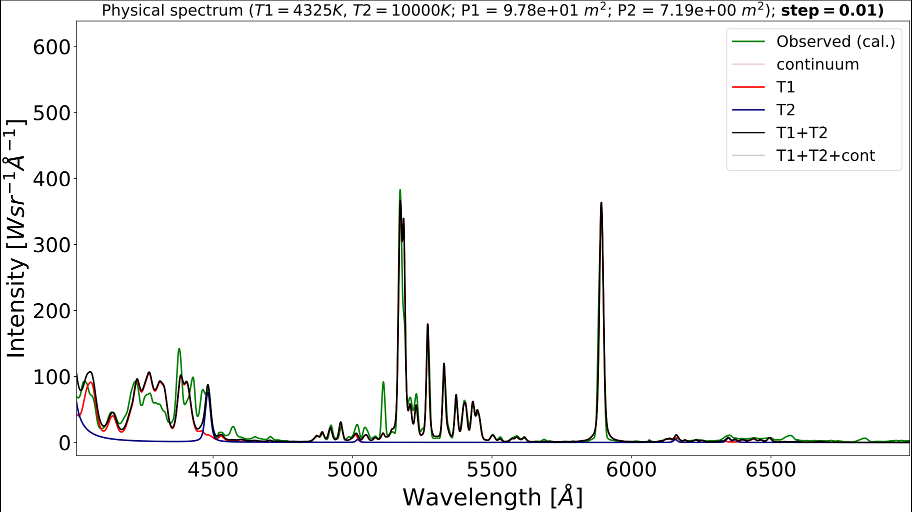
Physical fit from camera 214N-1 (T1 and T2)



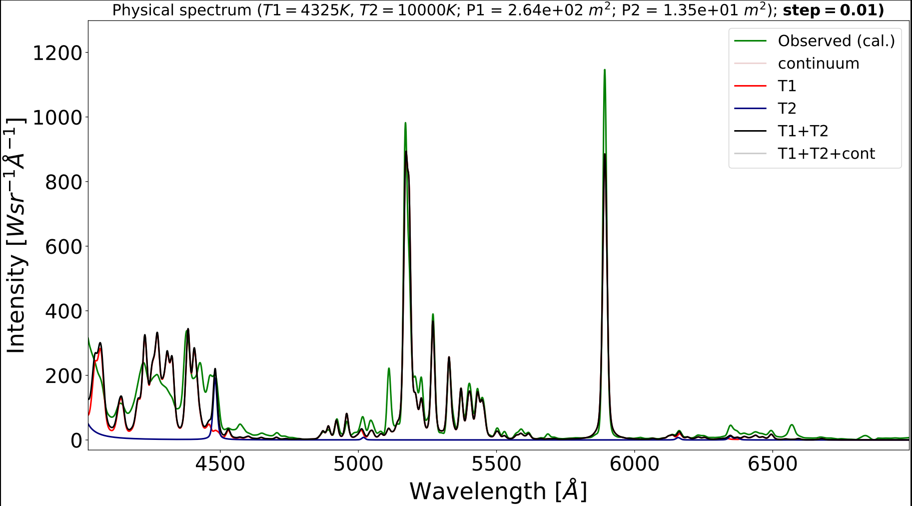
Physical fit from camera 214E-0 (T1 and T2)



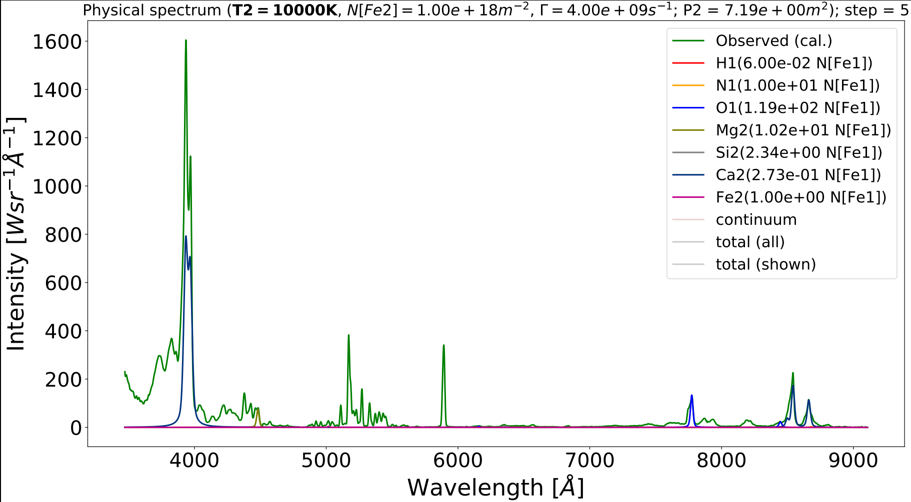
Physical fit from camera 214N-1 (T1 and T2)



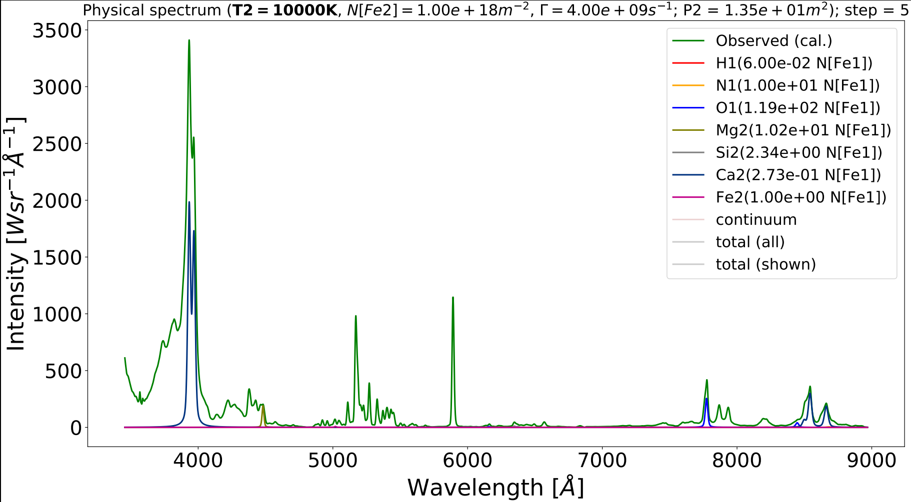
Physical fit from camera 214E-0 (T1 and T2)



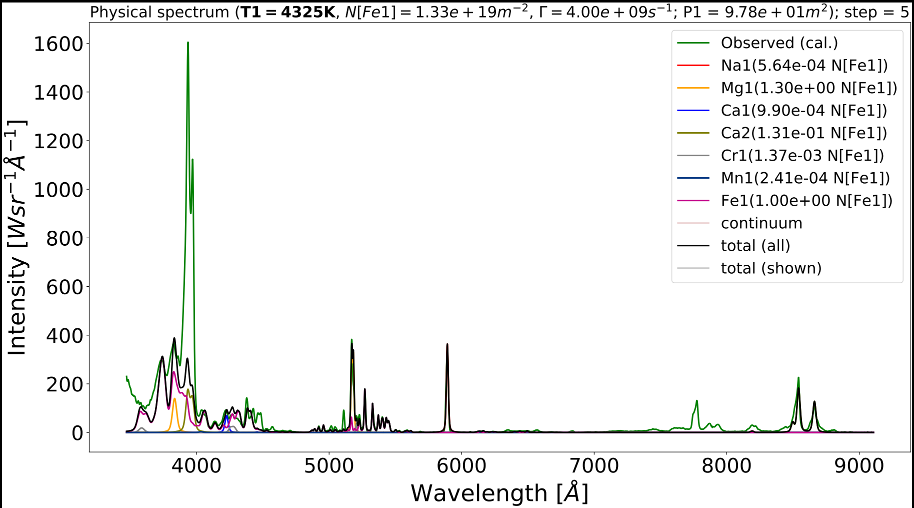
Physical fit from camera 214N-1 (T2)



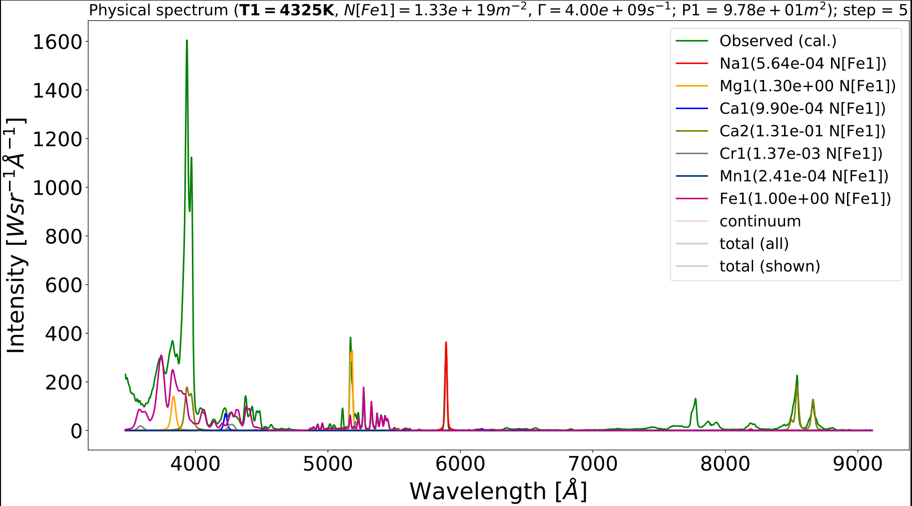
Physical fit from camera 214E-0 (T2)



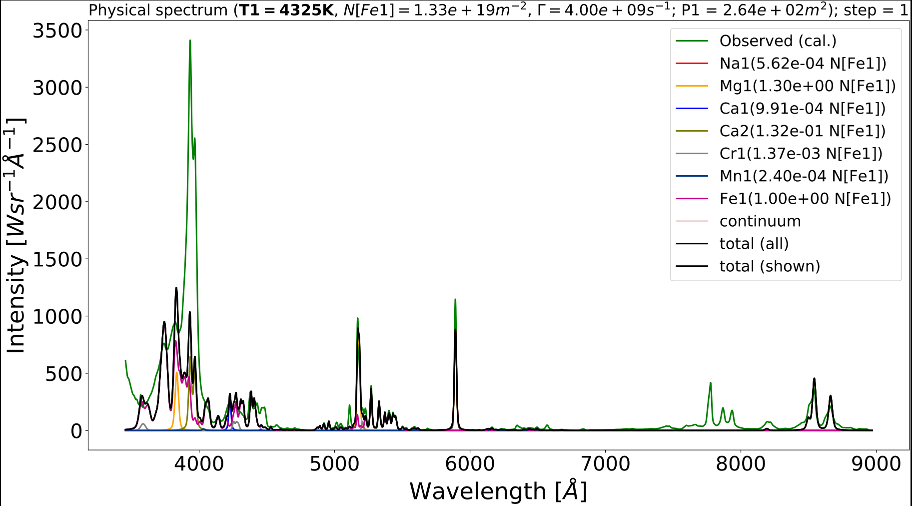
Physical fit from camera 214N-1 (T1)



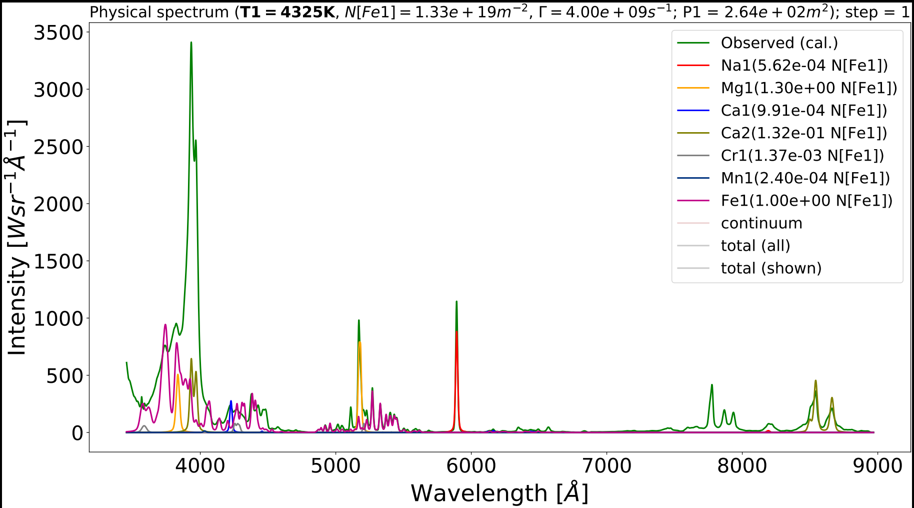
Physical fit from camera 214N-1 (T1)



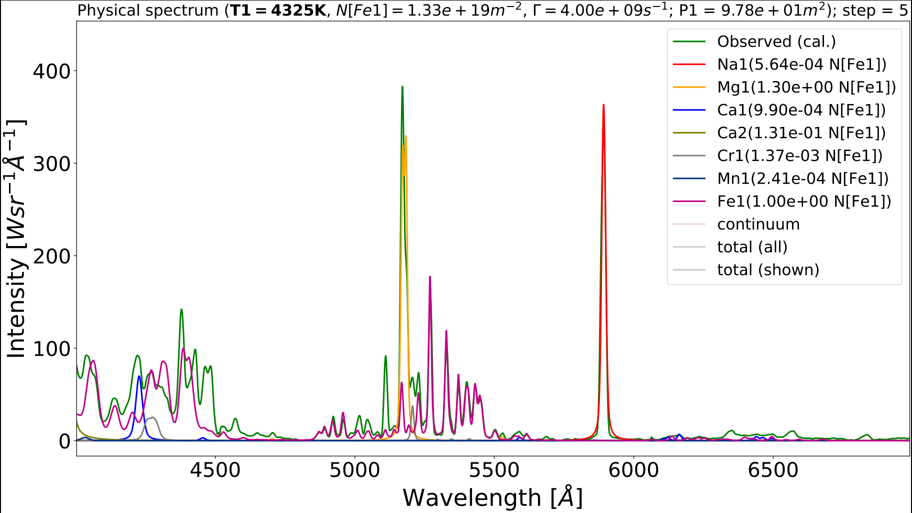
Physical fit from camera 214E-0 (T1)



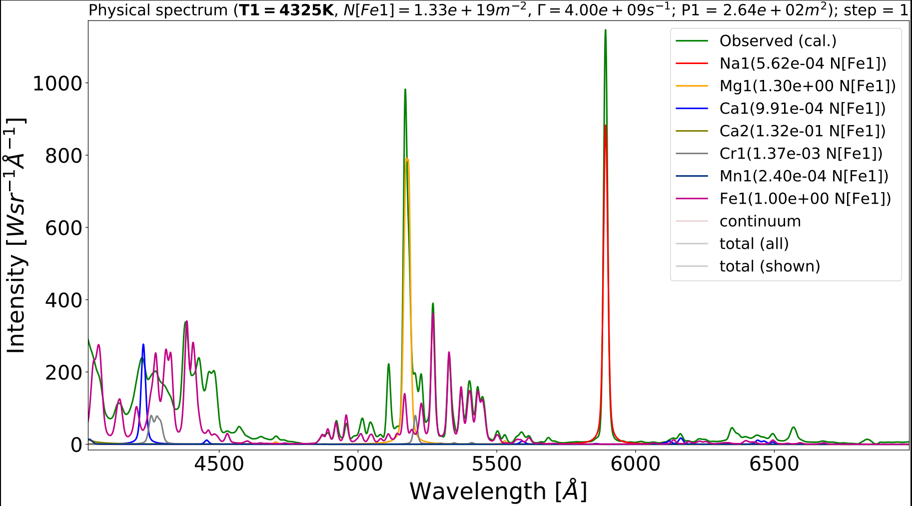
Physical fit from camera 214E-0 (T1)



Physical fit from camera 214N-1 (T1)



Physical fit from camera 214E-0 (T1)



Discussion (limitations)

- Results can only be trusted in the 4000-6000 (7000) Å range.
- Ca II is difficult to fit reliably (Ca I may help!).
- Absolute intensities are not reliable. Data from non-spectral observations may be used.
- Some lines are not in TDE (Fe I).
- Difficult to model the second component.
- So far, we were unable to model the continuum.

Discussion (breakthroughs)

- The developed software works on digital spectra.
  - Calibrates the spectrum quickly and efficiently.
  - Searches for best physical solution automatically.
  - All parameters can be manually adjusted.
- The assumption of TDE provides a reasonable model to fit most observed spectral lines.
- Relative line intensities from separate observations yield consistent results.

Next steps

- Ionisation correction.
- Calculation of relative element abundances.
- Estimation of uncertainties using multi-station data.
- Comparison of composition of Jupiter family and Halley-type cometary material.

THANK YOU