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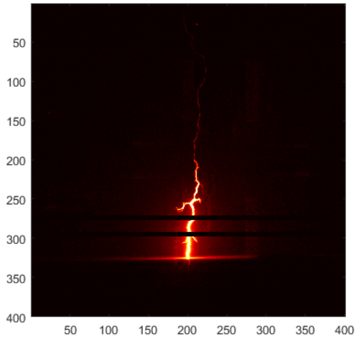


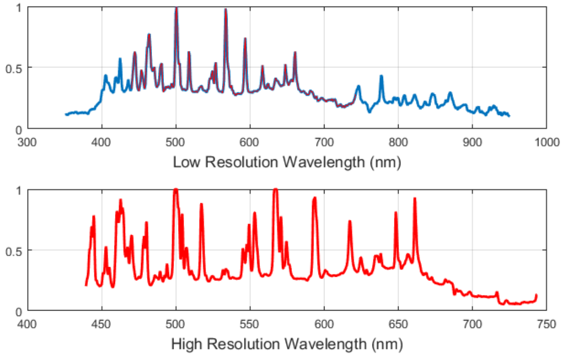


# Hyper-spectral, hyper-temporal lightning data collects

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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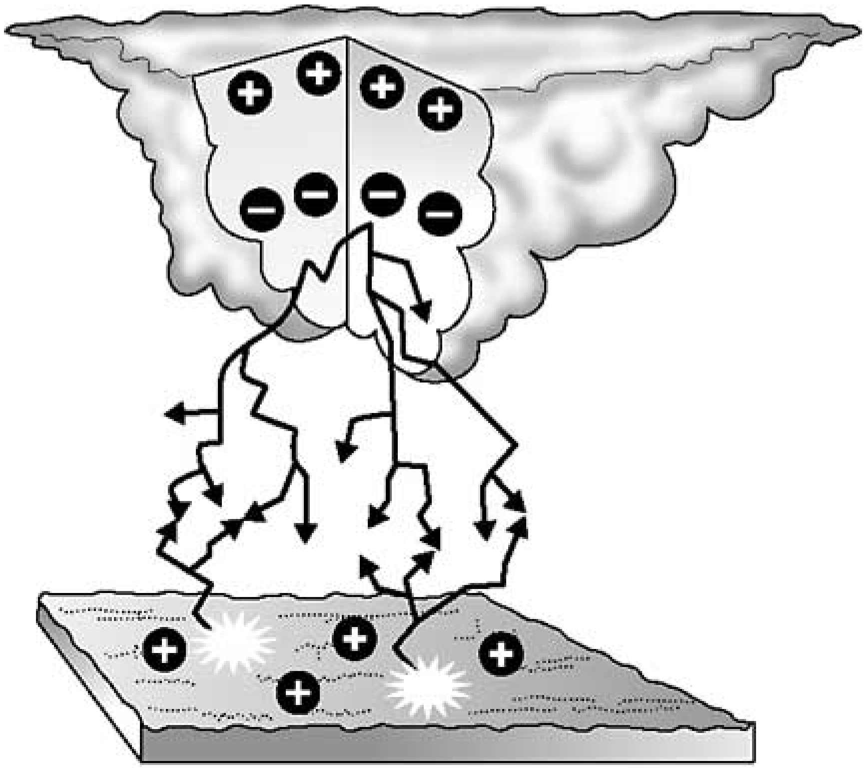
# Project Overview

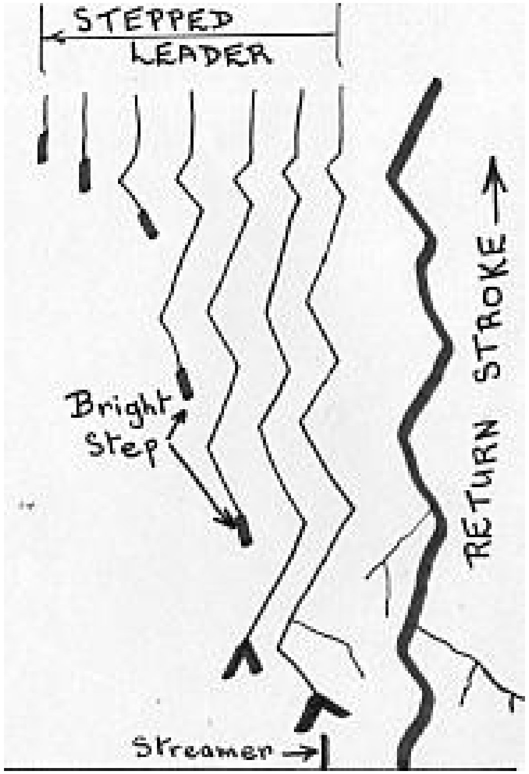
The lightning observations were made as part of a Laboratory Directed Research and Development (LDRD) project titled "Co-Design of Sensors and Analysis Methods for Optical Remote Sensing of Spectral-Temporal Signals." Primary team members and their contributions:

- Mark W. Smith – principal investigator. Developed visualization software.
- Michael Clemenson – led collection of lighting data and sensor calibration
- Braden Smith – helped collect lightning data and started analysis
- Anthony Tanbakuchi – designed spectrometers and guided construction
- Michael Montoya – helped setup and operate high speed sensors
- Byron Demosthenus – helped setup and operate high speed sensors
- Julius Yellowhair – hosted us at the SNL solar tower control building
- Josh Zollweg – working on radiometric calibration of data
- Adele Doser – works on analysis and discrimination algorithms
- Jarrod Edwards – is developing a first principles lightning model
- Phil Dreike – is mentoring Jarrod Edwards

# Basic Physics



Elizabeth Morales




"An electrically active thundercloud may be regarded as an electrostatic generator suspended in an atmosphere of low electrical conductivity. It is situated between two concentric conductors, namely the surface of the earth and the electrosphere…"
- D. J. Malan (1967)

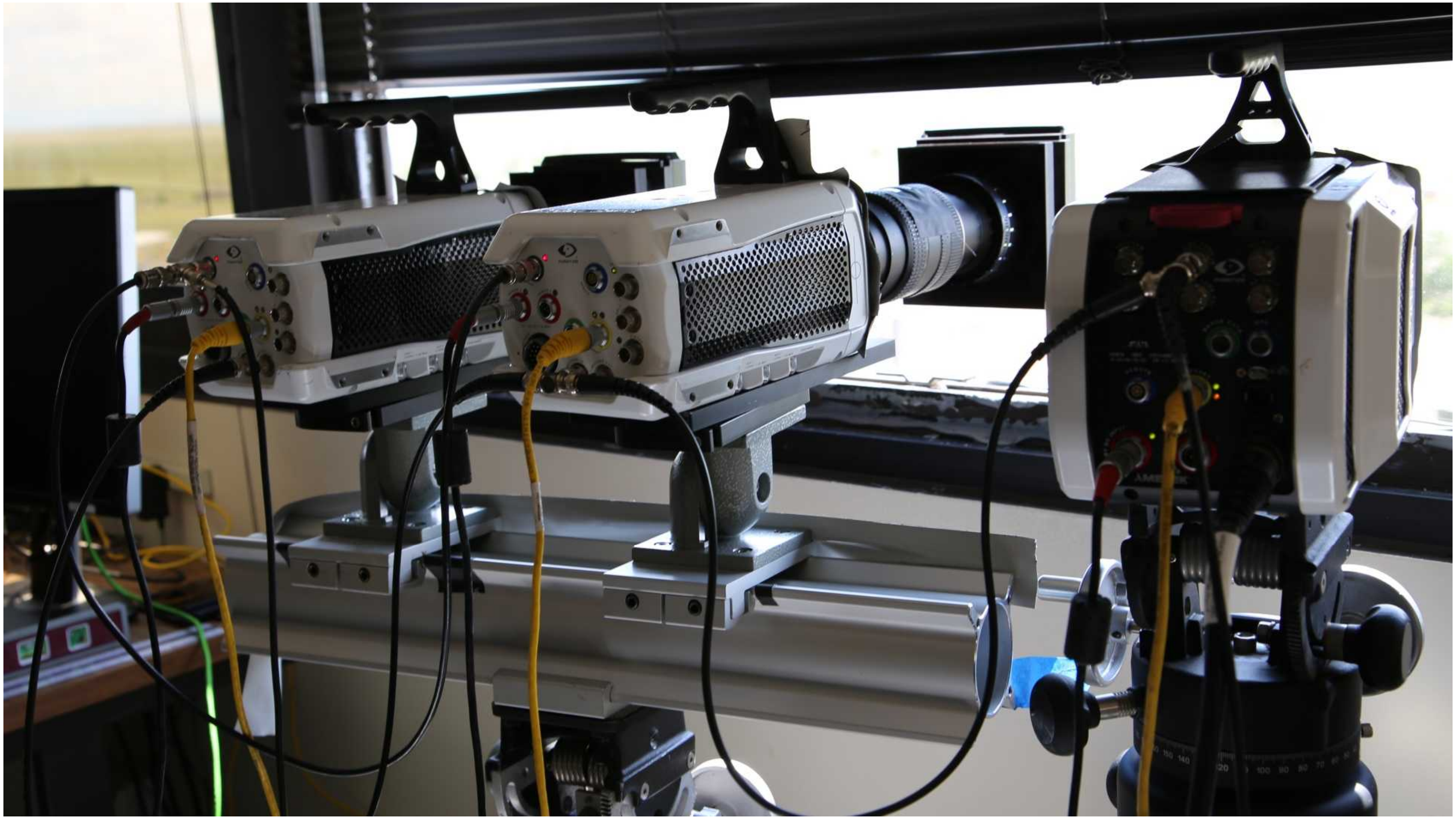
# Some Numbers

| Parameter | Value | Units |
|---|---|---|
| Speed at which stepped leader moves down | $(0.8 – 8) \times 10^5$ | $m\ s^{-1}$ |
| Speed at which return strokes move up | $(1 – 2) \times 10^8$ | $m\ s^{-1}$ |
| Channel temperature of return strokes | 30,000 | K |
| Current rise time (10%-90%) of first return stroke | ≈ 5 | µS |
| Rise time (10%-90%) of subsequent strokes | 0.3 – 0.6 | µS |
| Current rise time (10%-90%) of M-component | 0.3 – 0.5 | mS |
| Interval between multiple return strokes | 95% > 7<br>5% > 150 | mS |
| Typical number of strokes per flash | 3 – 5 | |

# Lightning Channel

- Core
  - Effective diameter roughly a few mms
  - High temp, high degree of ionization
  - Primarily singly ionized atoms including N II
- Outer sheath
  - Effective diameter roughly a few cm
  - Carries most of the current and dissipates most of the power
  - Partially ionized and luminous, but lower temp than core

# Sensor Suite



# Sensor Specifications

| | 11 July 2015 to 21 July 2015 |
|---|---|
| Low Resolution Spectrometer | Dispersion = 0.79 nm/pixel, FWHM = 1.2 nm<br>Frame rate = 400 k/s, Exposure = 1.0 – 1.7 μS |
| High Resolution Spectrometer | Dispersion = 0.17 nm/pixel, FWHM = 0.38 nm<br>Frame rate = 350 – 400 k/s, Exposure = 2.0 – 2.4 μS |
| Imager | Frame rate = 25 – 50 k/s, Exposure = 10.0 μS |

| | 22 July 2015 to 22 August 2015 |
|---|---|
| Low Resolution Spectrometer | Dispersion = 1.10 nm/pixel, FWHM = 2.5 nm<br>Frame rate = 400k/s, Exposure = 0.5 – 0.6 μS |
| High Resolution Spectrometer | Dispersion = 0.24 nm/pixel, FWHM = 0.66 nm<br>Frame rate = 250 – 275 k/s, Exposure = 3.0 – 3.3 μS |
| Imager | Frame rate = 12.5 – 50 k/s, Exposure = 7.0 – 10.0 μS |

# Scene as viewed by the high speed imager

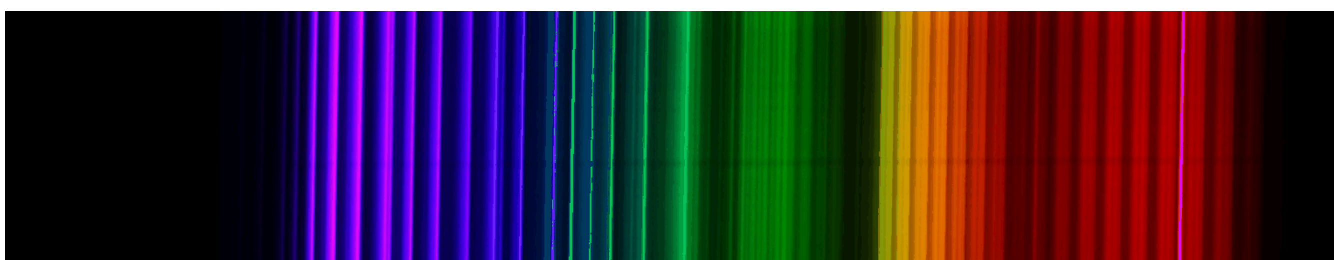
# Slit-less Spectrometer

Slit-less transmission grating design: enables high speed imaging of point or line sources.
Modular design allows multiple focal lengths and wedge angles.
Can print new modules as needed with 4 day turn around.
Spectral range: 400-800 nm
Spectra per second: 450,700 with Phantom Camera
Configurations:

- 400 nm spread @ 1.1 nm res
- 400 nm spread @ 0.5 nm res
- 300 nm spread @ 0.23 nm res
- 240 nm spread @ 0.2 nm res
- 120 nm spread @ 0.1 nm res

With SLR can get ~10x resolution for non-temporal collects.

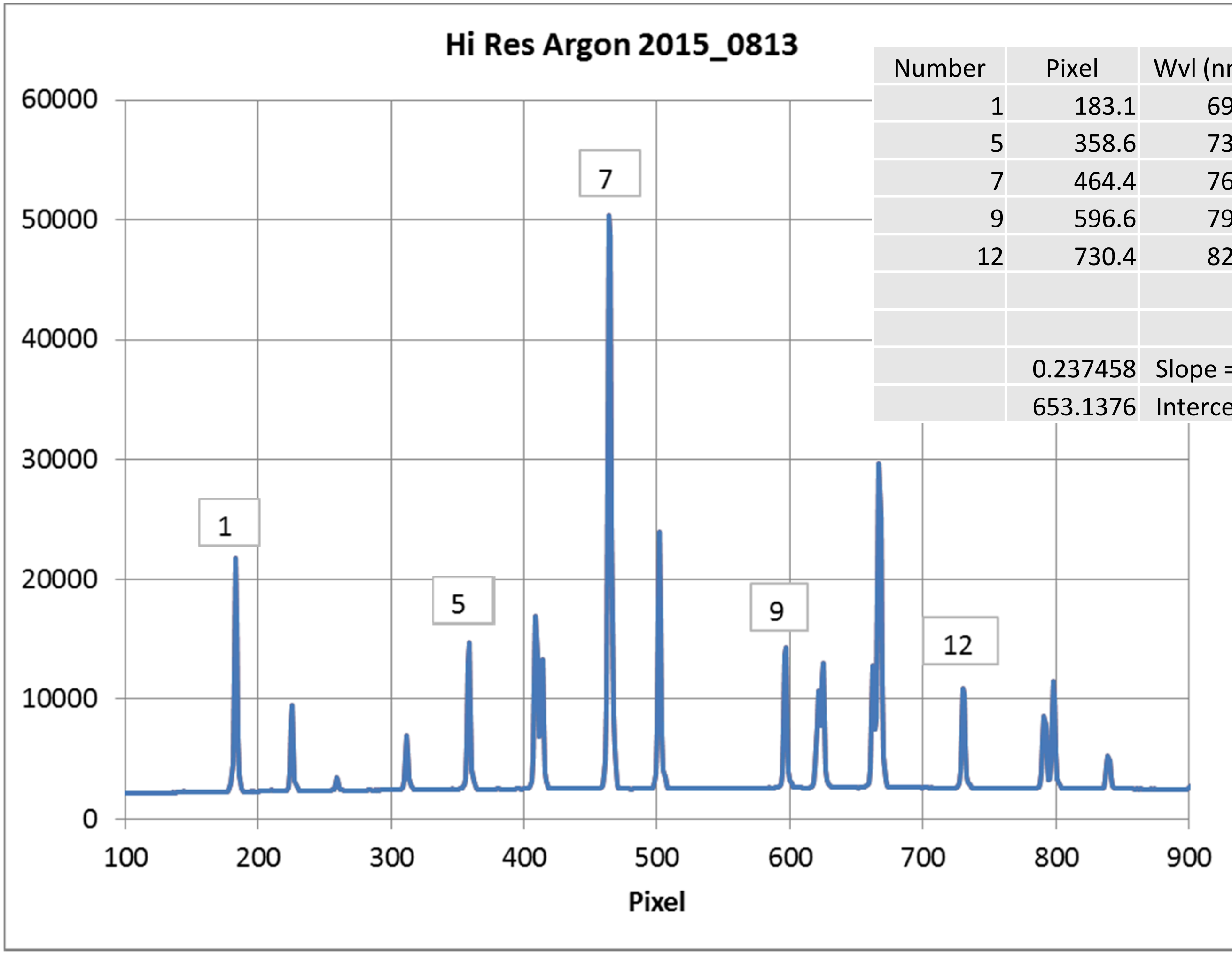
Spectrum of low pressure discharge lamp containing air



# Spectral Calibration

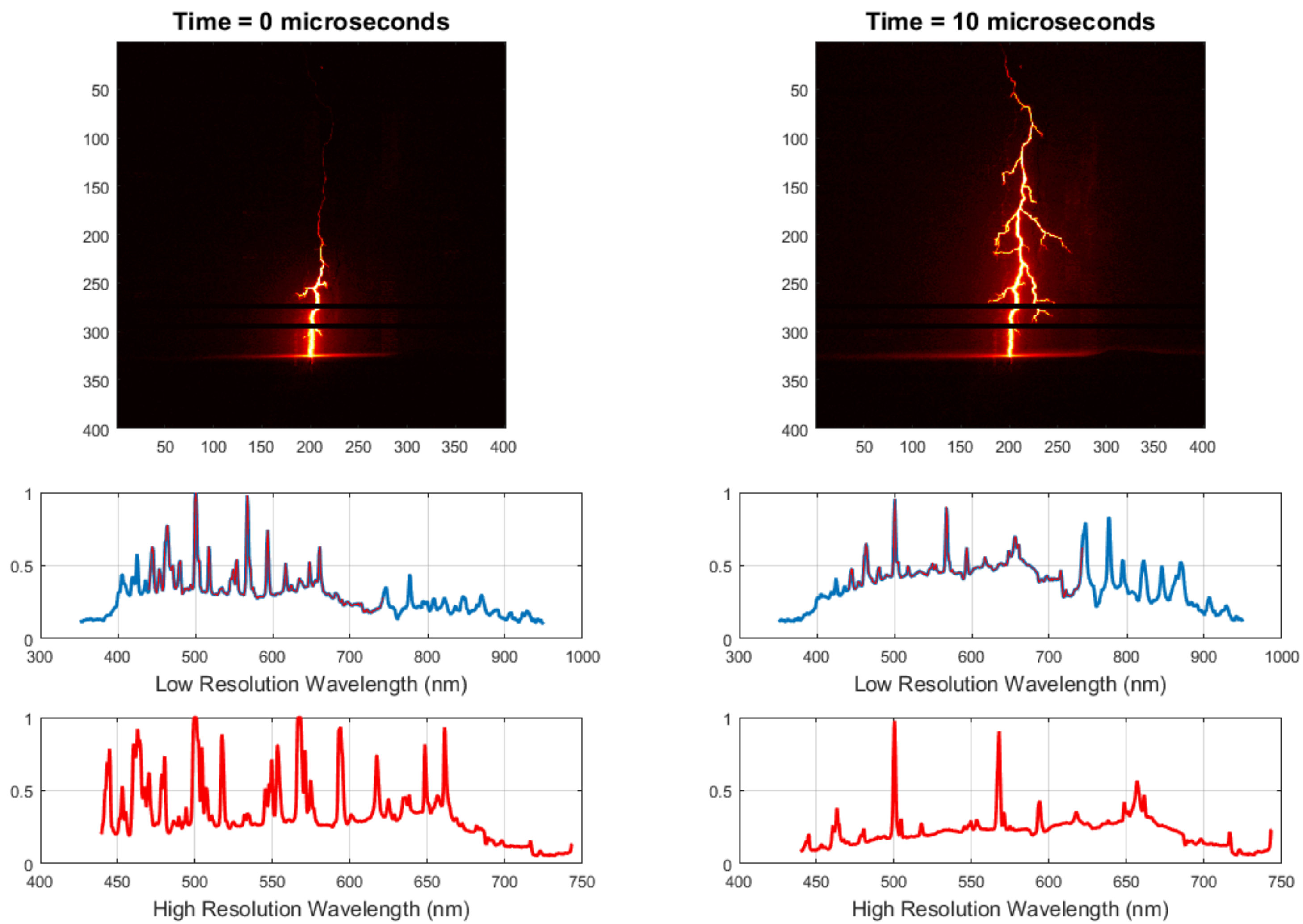
- Calibrate spectrometer dispersion with low pressure argon lamp
- Use low resolution data that show $0^{th}$ and $1^{st}$ order spectra and the corresponding images to calculate the offset between image pixels and location of $0^{th}$ order light in low resolution channel
- Use results from these two steps to calculate an approximate wavelength scale for each strike
- Up sample low resolution spectra and correlate to known lines in lightning spectra to refine results
- Correlate the high resolution spectra to the fully calibrated, up sampled low resolution spectra

# Argon Lamp Lines




| Number | Pixel | Wvl (nm) | Lin Fit | Residual |
|---|---|---|---|---|
| 1 | 183.1 | 696.5 | 696.616 | 0.116 |
| 5 | 358.6 | 738.4 | 738.290 | -0.110 |
| 7 | 464.4 | 763.5 | 763.413 | -0.087 |
| 9 | 596.6 | 794.8 | 794.805 | 0.005 |
| 12 | 730.4 | 826.5 | 826.577 | 0.077 |
| | | | | |
| | | | | |
| | 0.237458 | Slope = dispersion = nm/pixel | | |
| | 653.1376 | Intercept | | |

# Example Data: Part 1



# Example Data: Part 2