Lightning Spectroscopy

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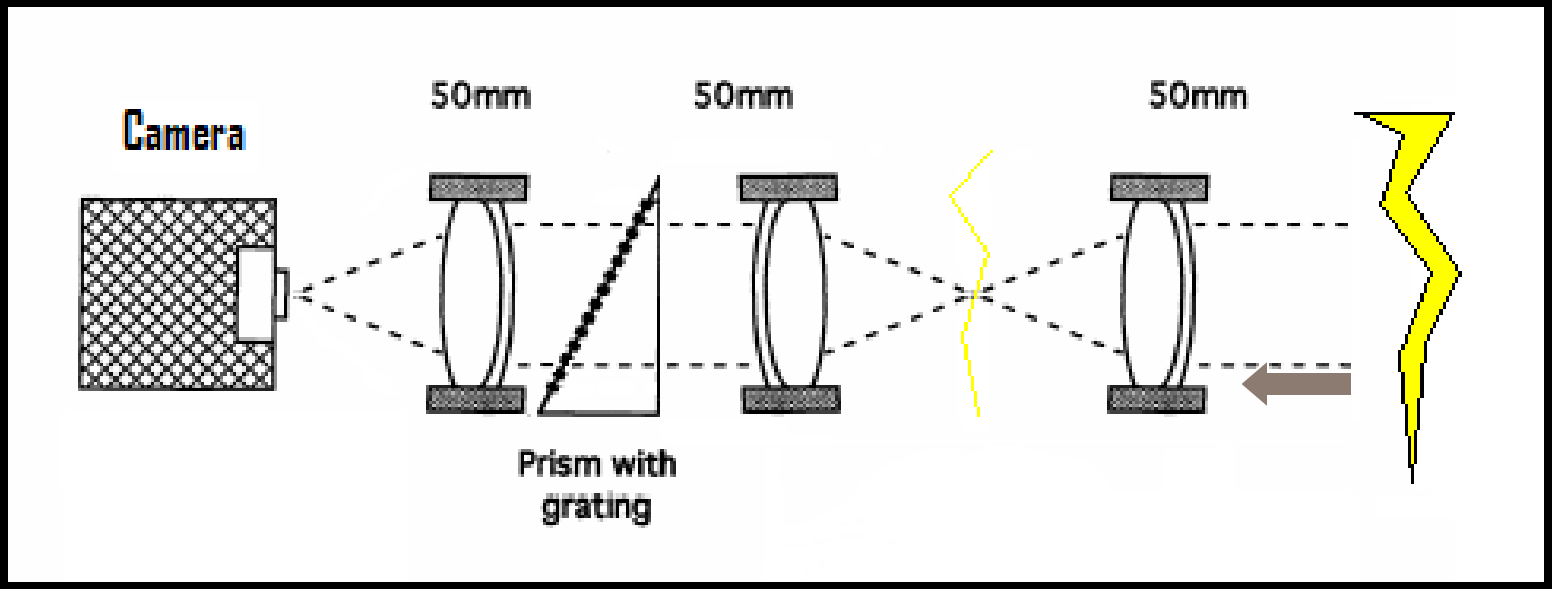
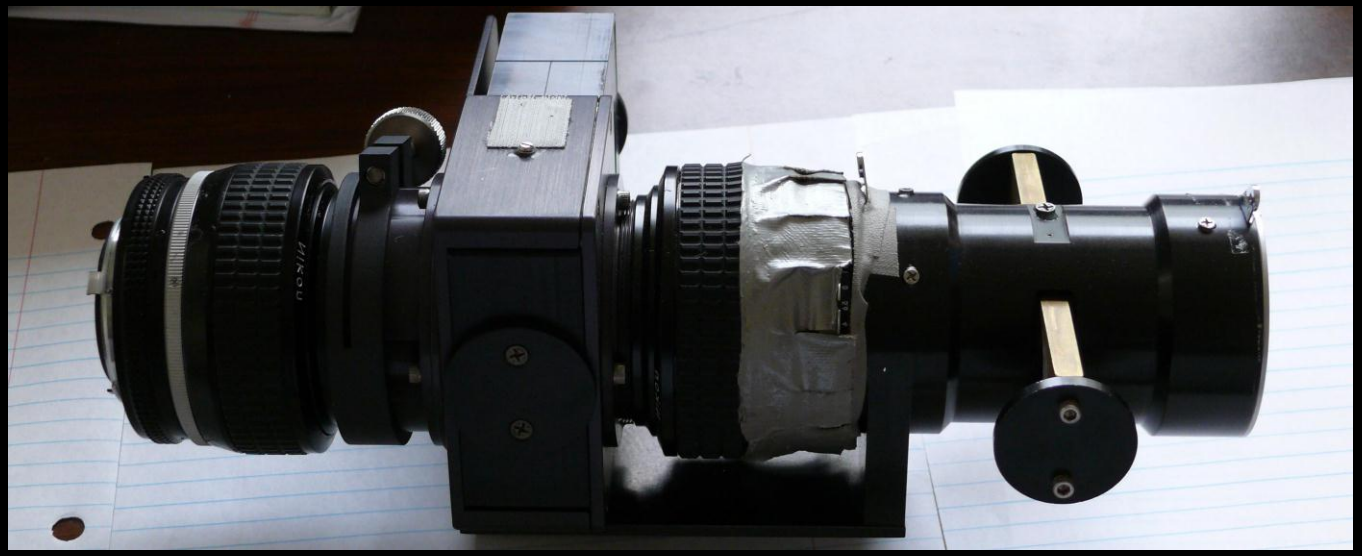
Spectral Information

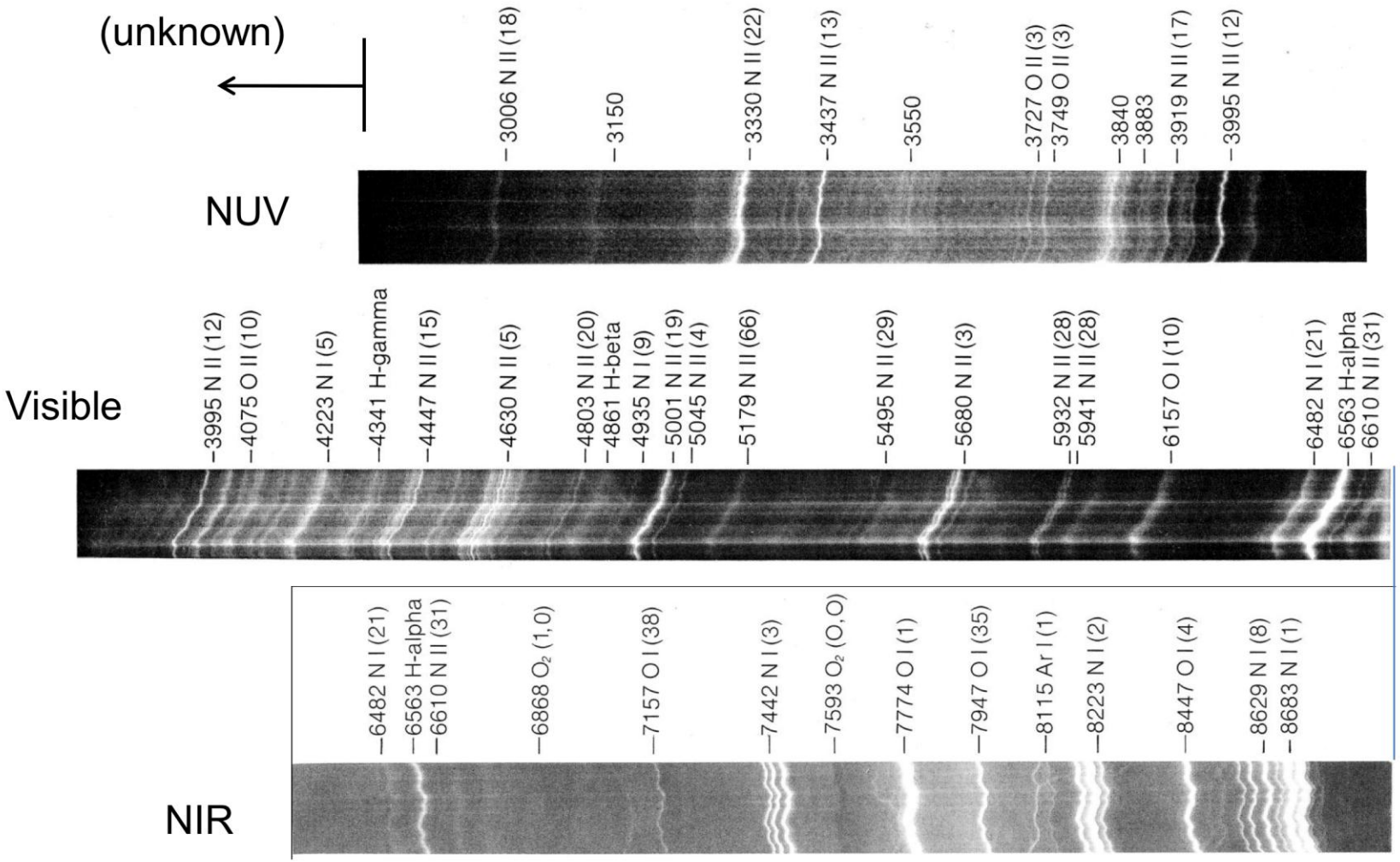
- Phantom v710
  - 670k fps
- 5 Angstroms/pixel dispersion
- Natural and Triggered Lightning at ICLRT

Spectrometer Design



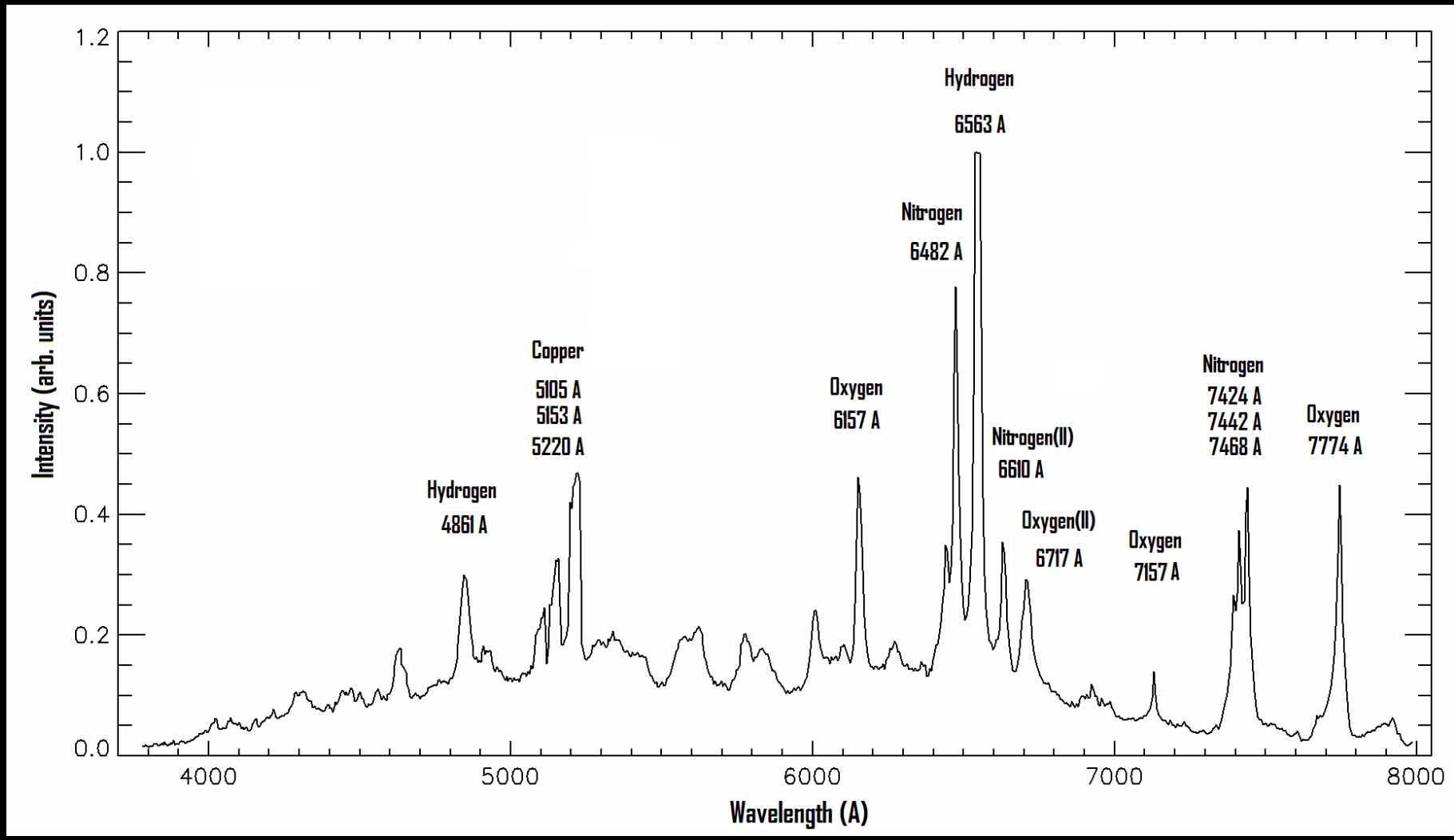


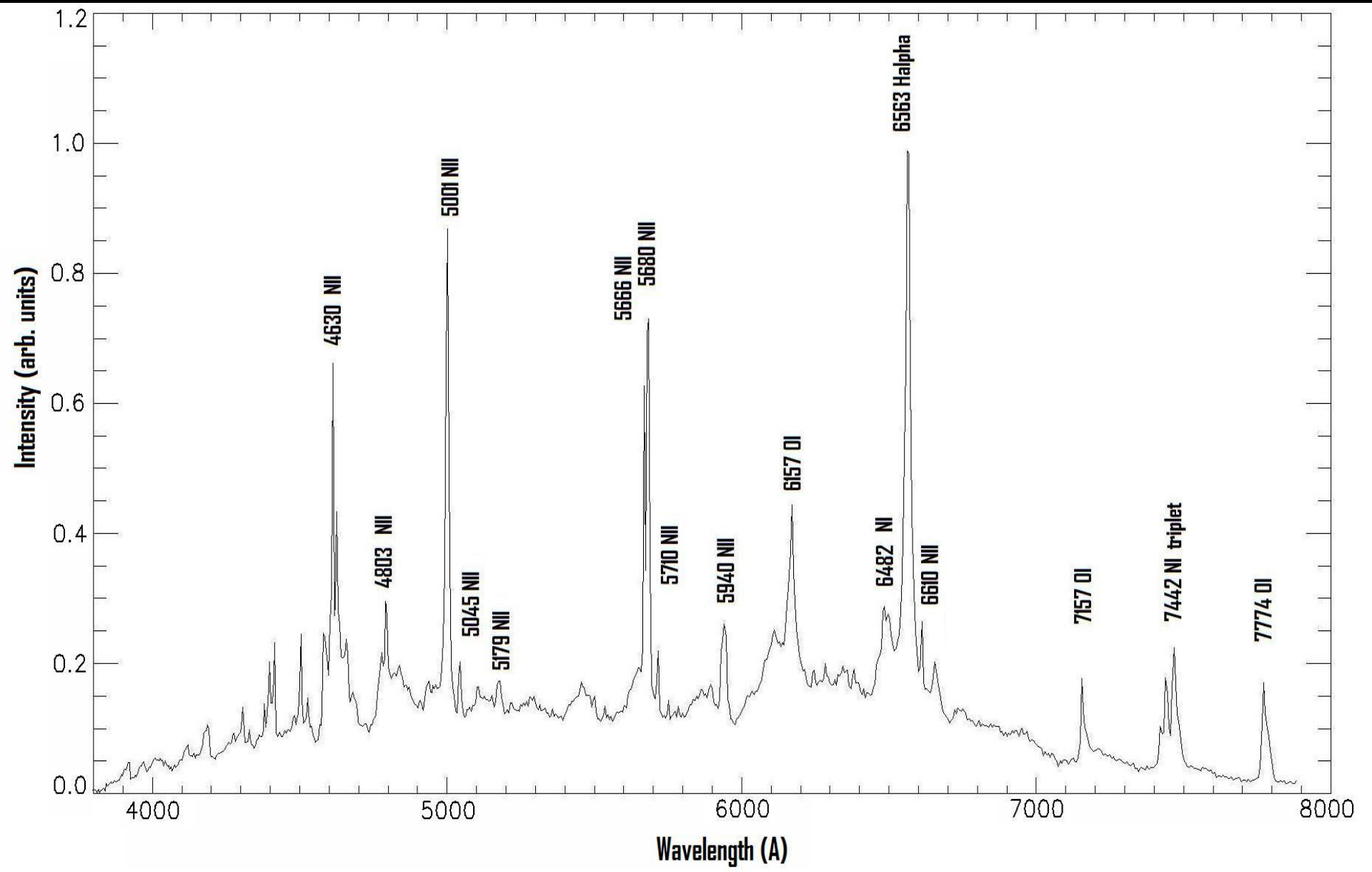
Spectrum of Lightning 300-900 nm



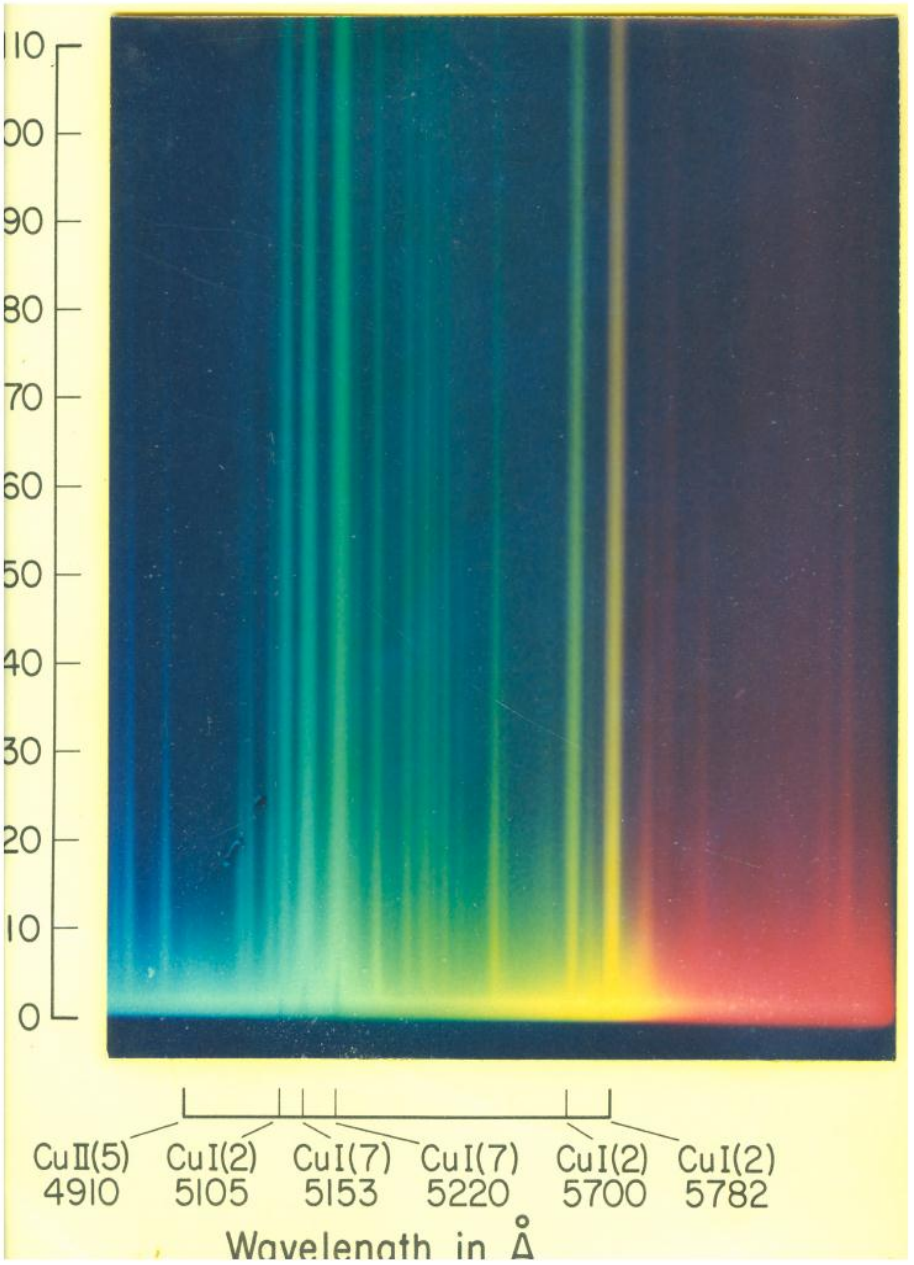
[From Salanave, L. (1980), *Lightning and its Spectrum*, Univ. of Arizona Press]

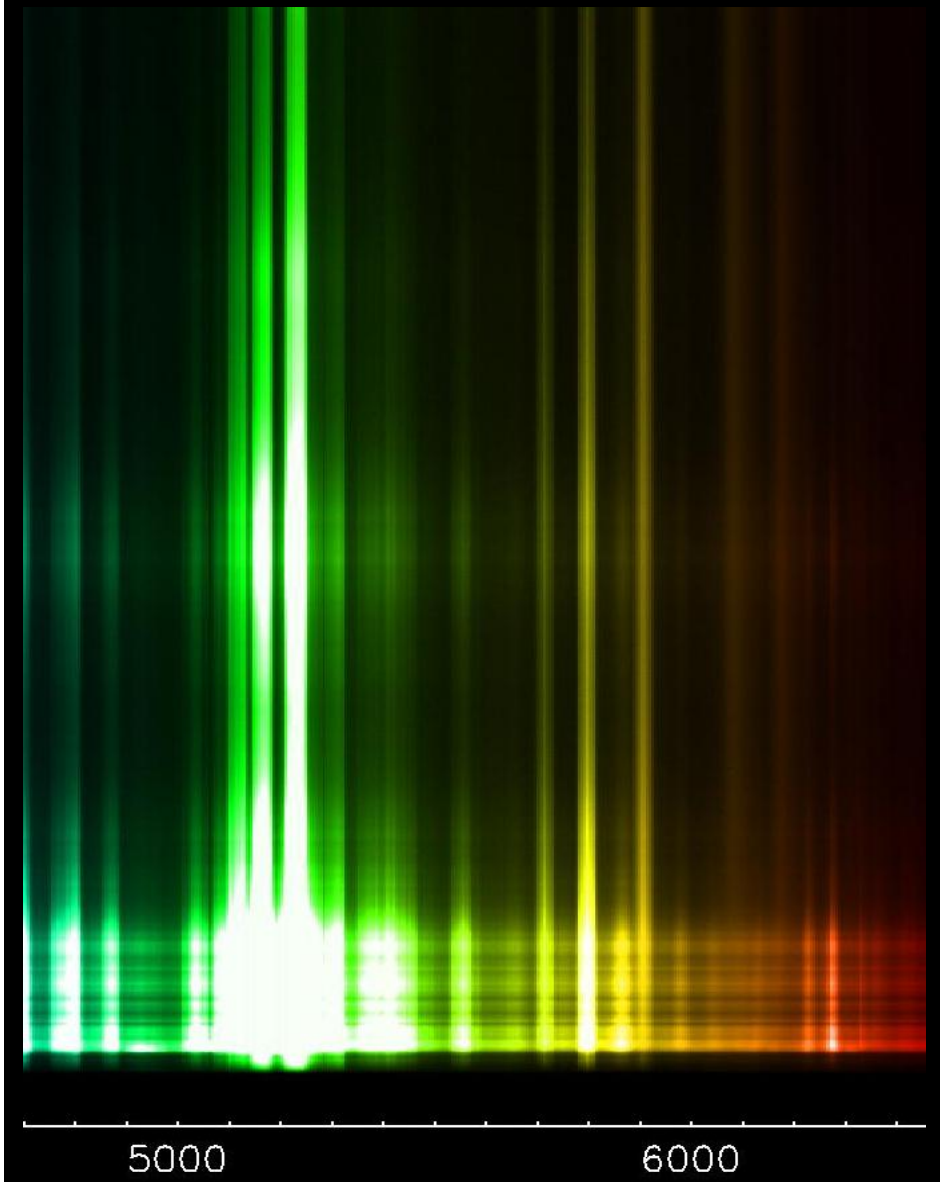
Sample Spectra

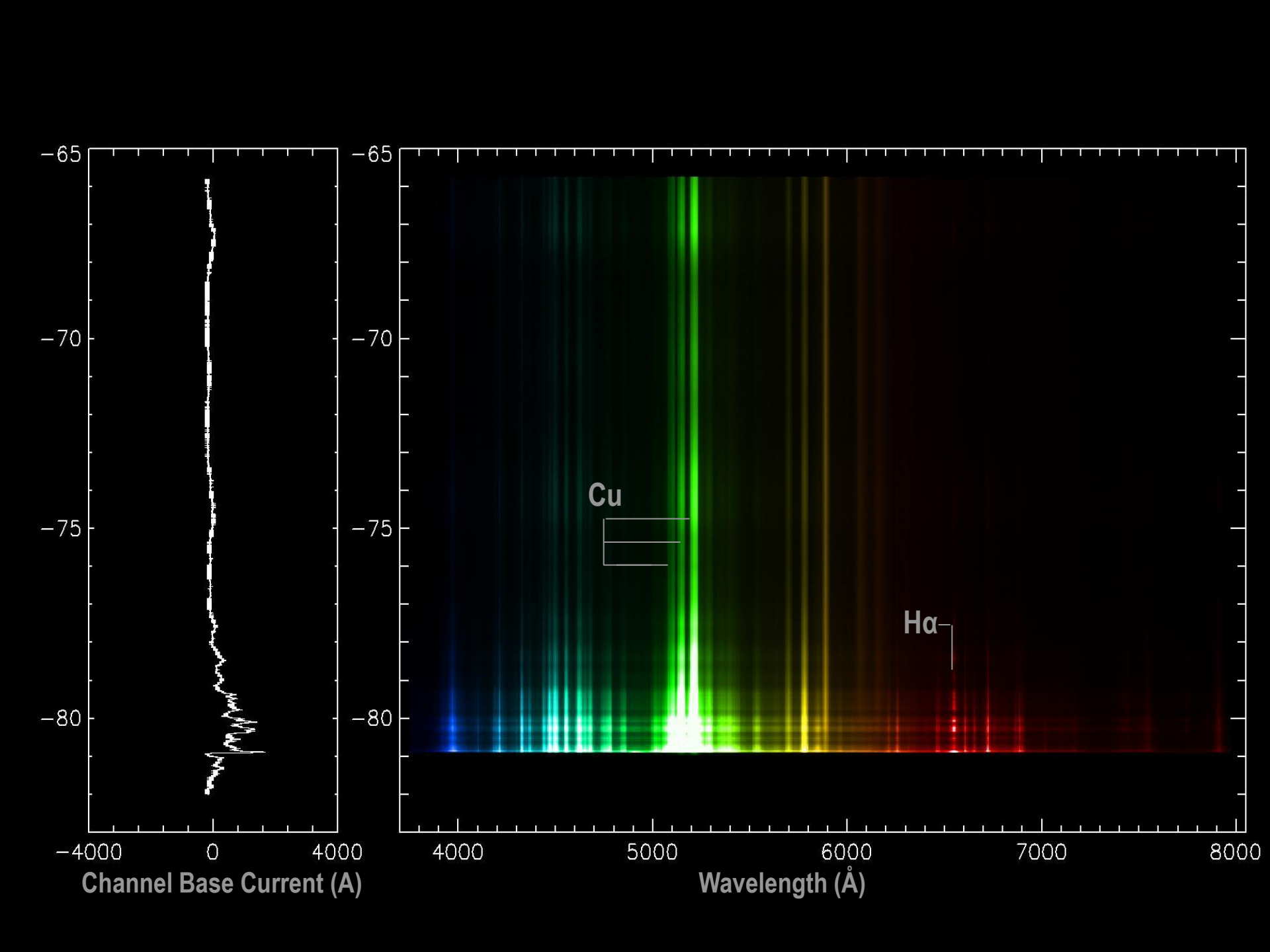


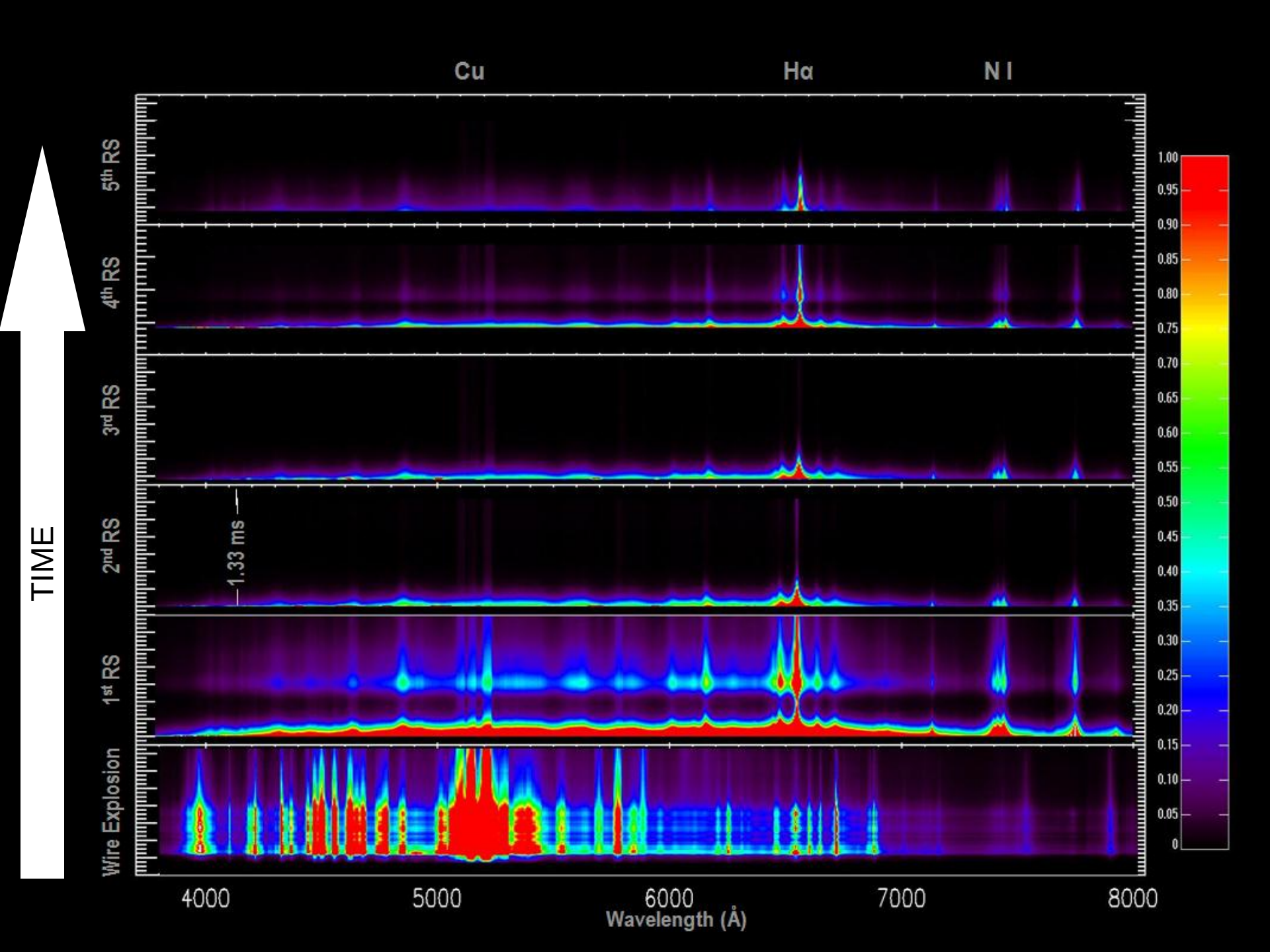

Intensity (arb. units)
Wavelength (A)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4000
5000
6000
7000
8000
4630 NII
4803 NII
5001 NII
5045 NII
5179 NII
5666 NII
5680 NII
5710 NII
5940 NII
6157 OI
6482 NI
6563 Halpha
6610 NII
7157 OI
7442 NI triplet
7774 OI

Time-Resolved Spectrum of a 4-Meter Exploding Enamel-Covered Copper Wire






−65
−70
−75
−80
−4000
0
4000
Channel Base Current (A)
−65
−70
−75
−80
4000
5000
6000
7000
8000
Wavelength (Å)
Cu
Hα

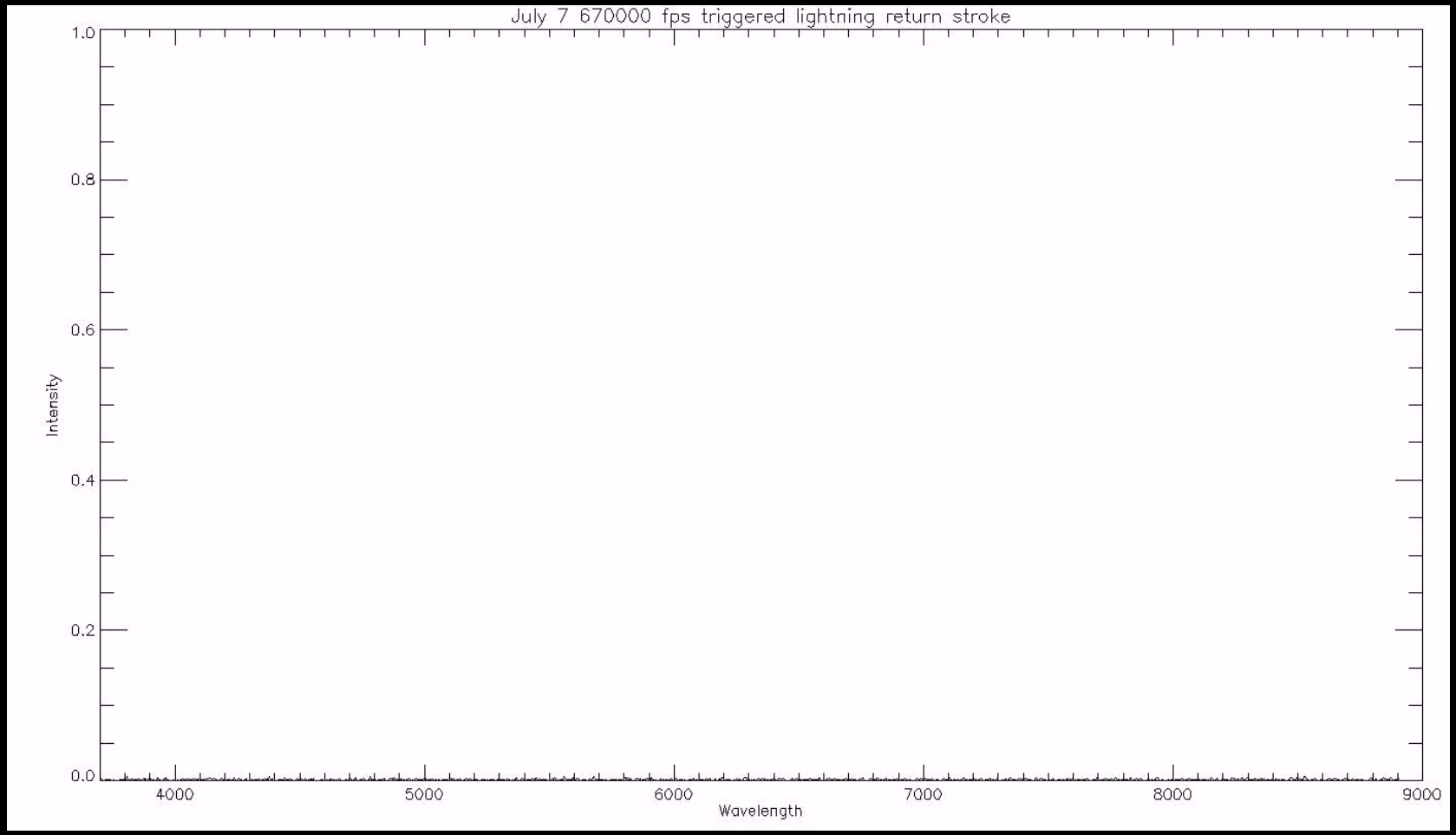

Cu
Hα
N I
5th RS
4th RS
3rd RS
2nd RS
1st RS
Wire Explosion
1.33 ms
TIME
4000
5000
6000
7000
8000
Wavelength (Å)
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0

Videos

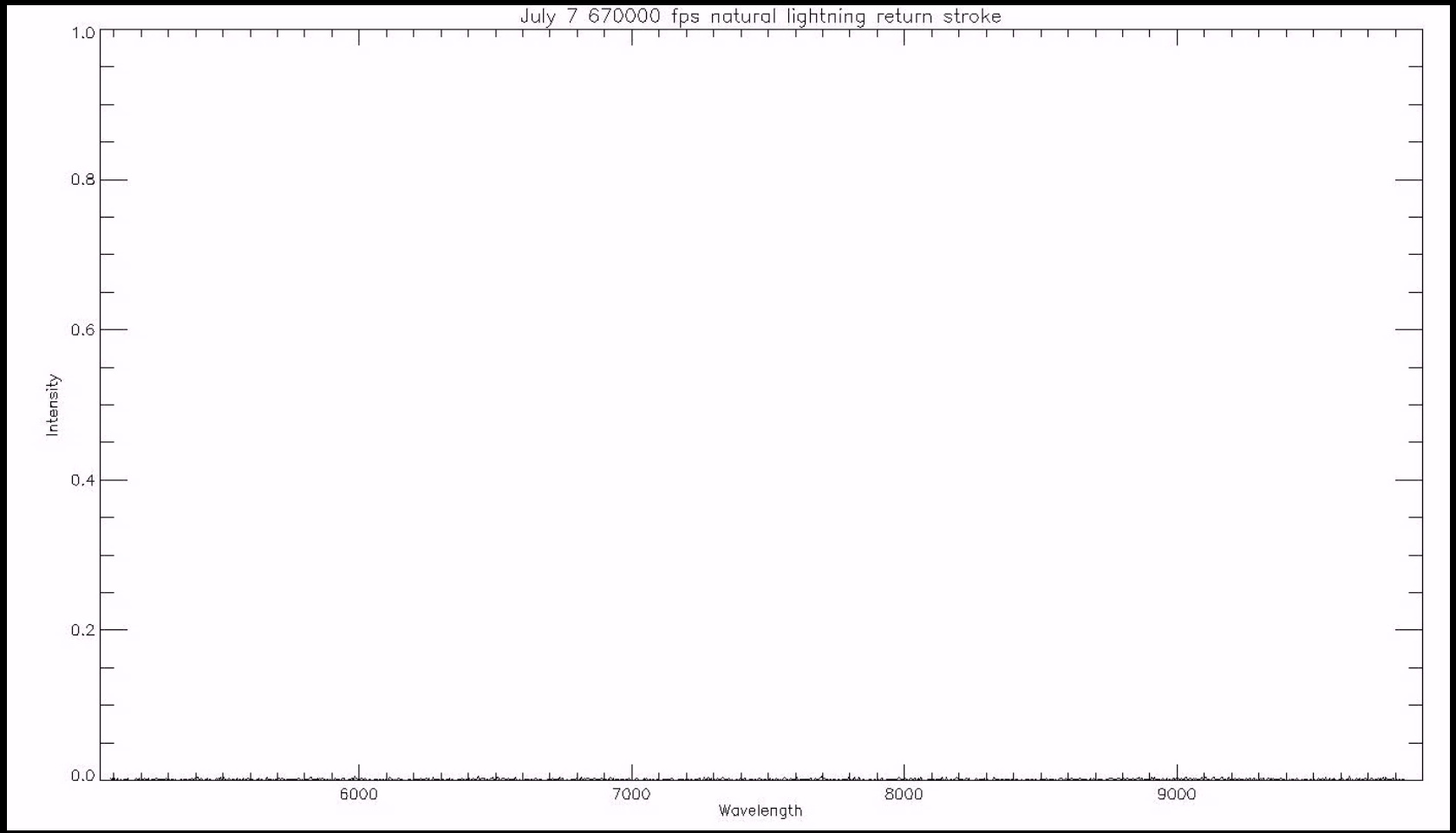
Triggered Lightning

Natural

670,000 fps triggered return stroke

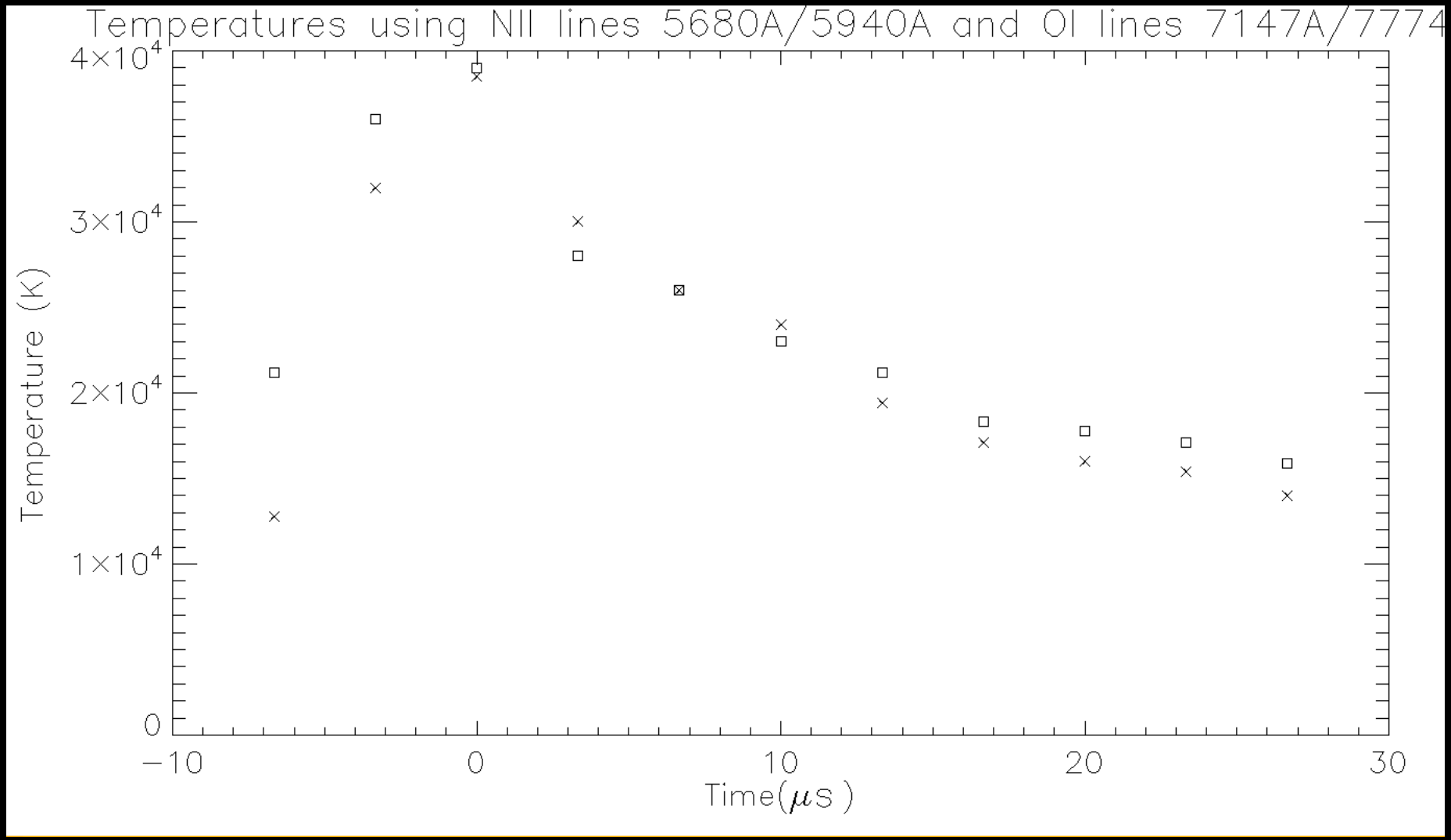


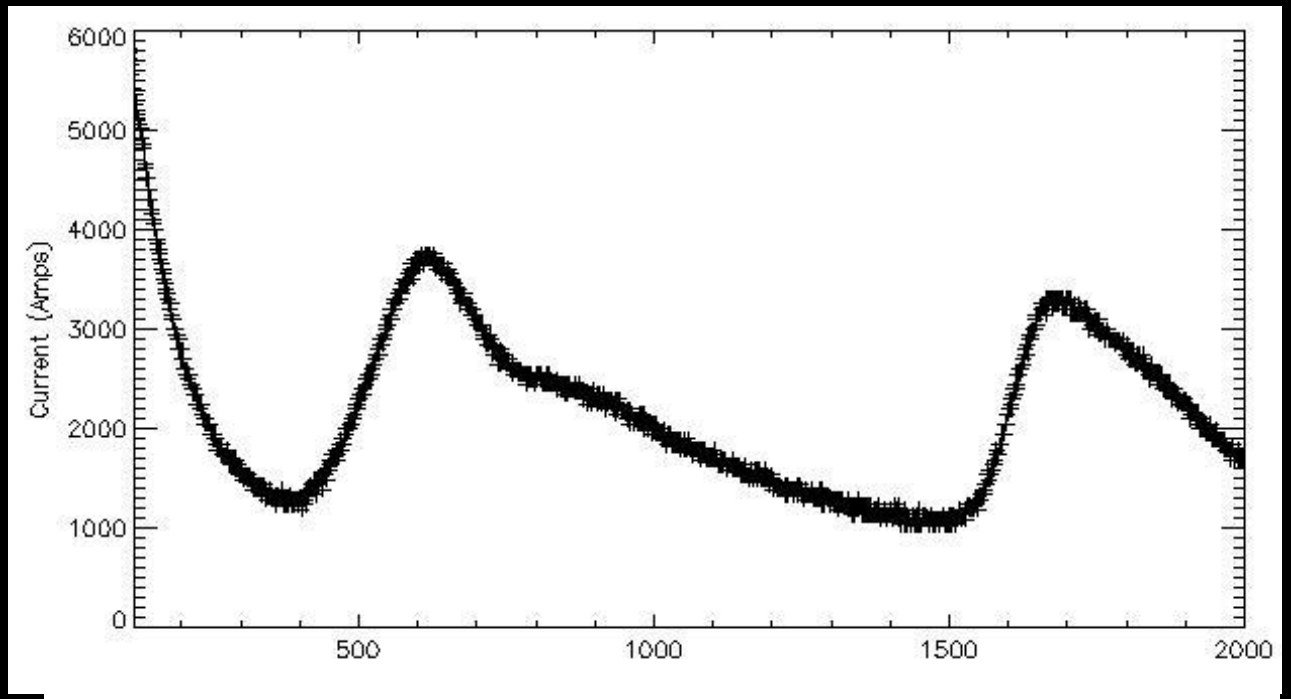
670,000 fps natural return stroke

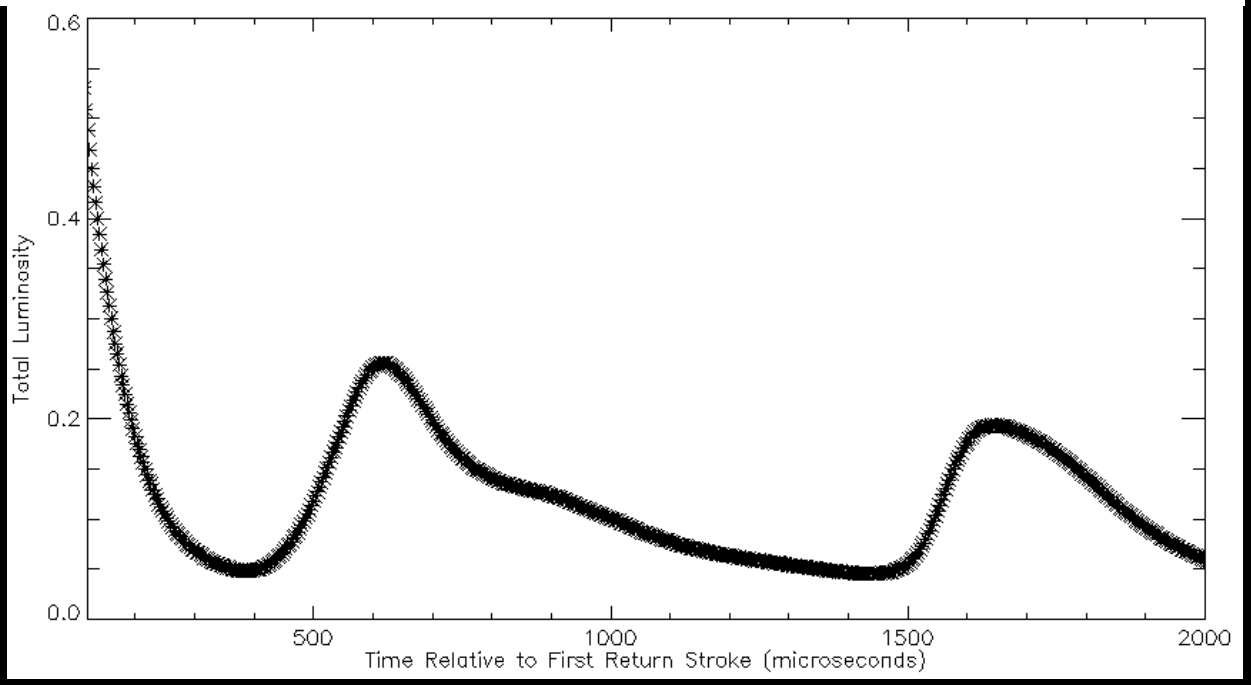


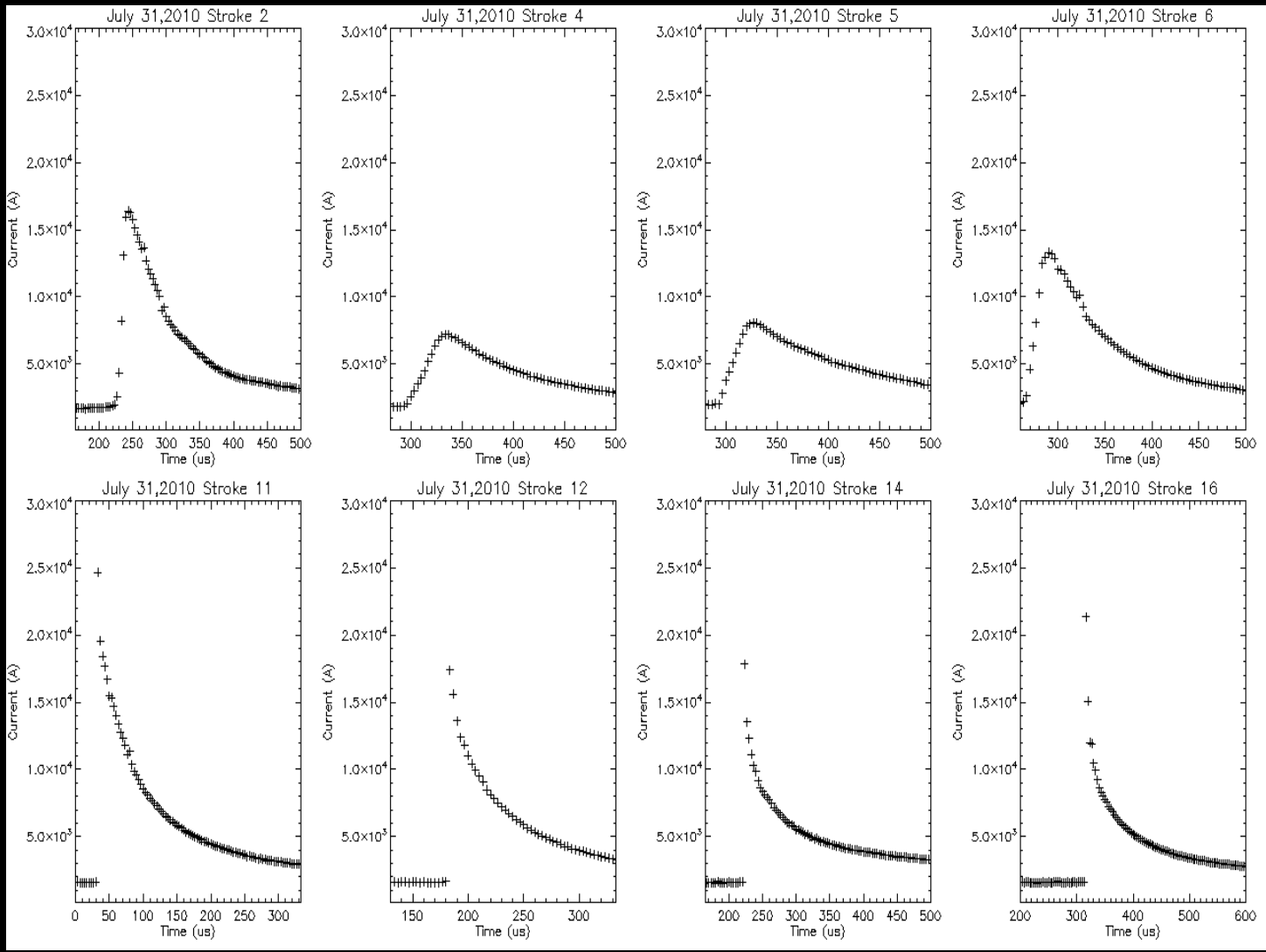
Physical Properties

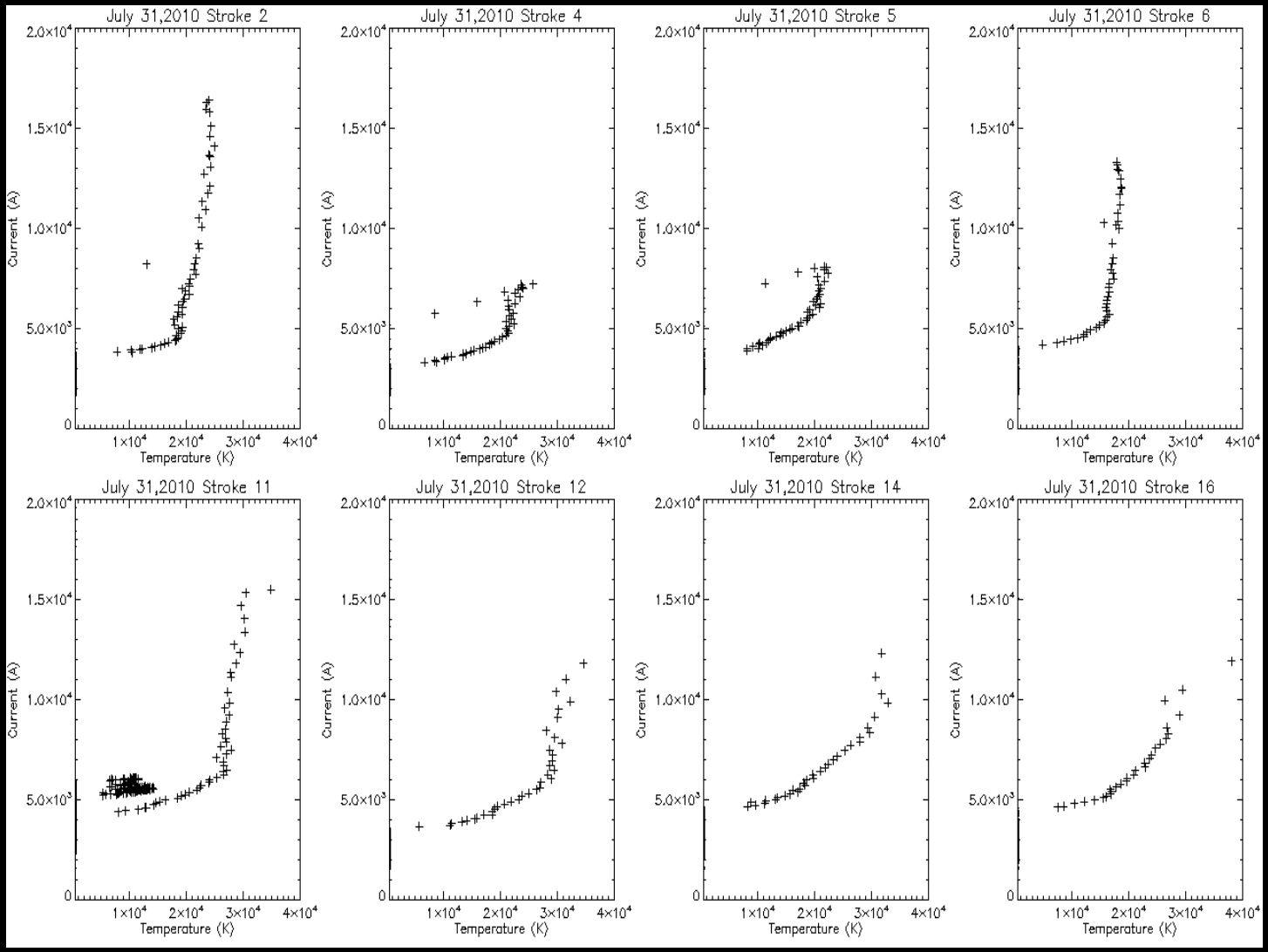
- Temperature
  - Ratios of Lines (M. Prueitt and R. Orville)
- Number Density
  - FWHM H-alpha
  - Ratio of Intensities of Singly Ionized lines to Neutral Lines of the same species
- Luminosity
  - Integrating over the entire spectrum
- Confinement
- Conductivity

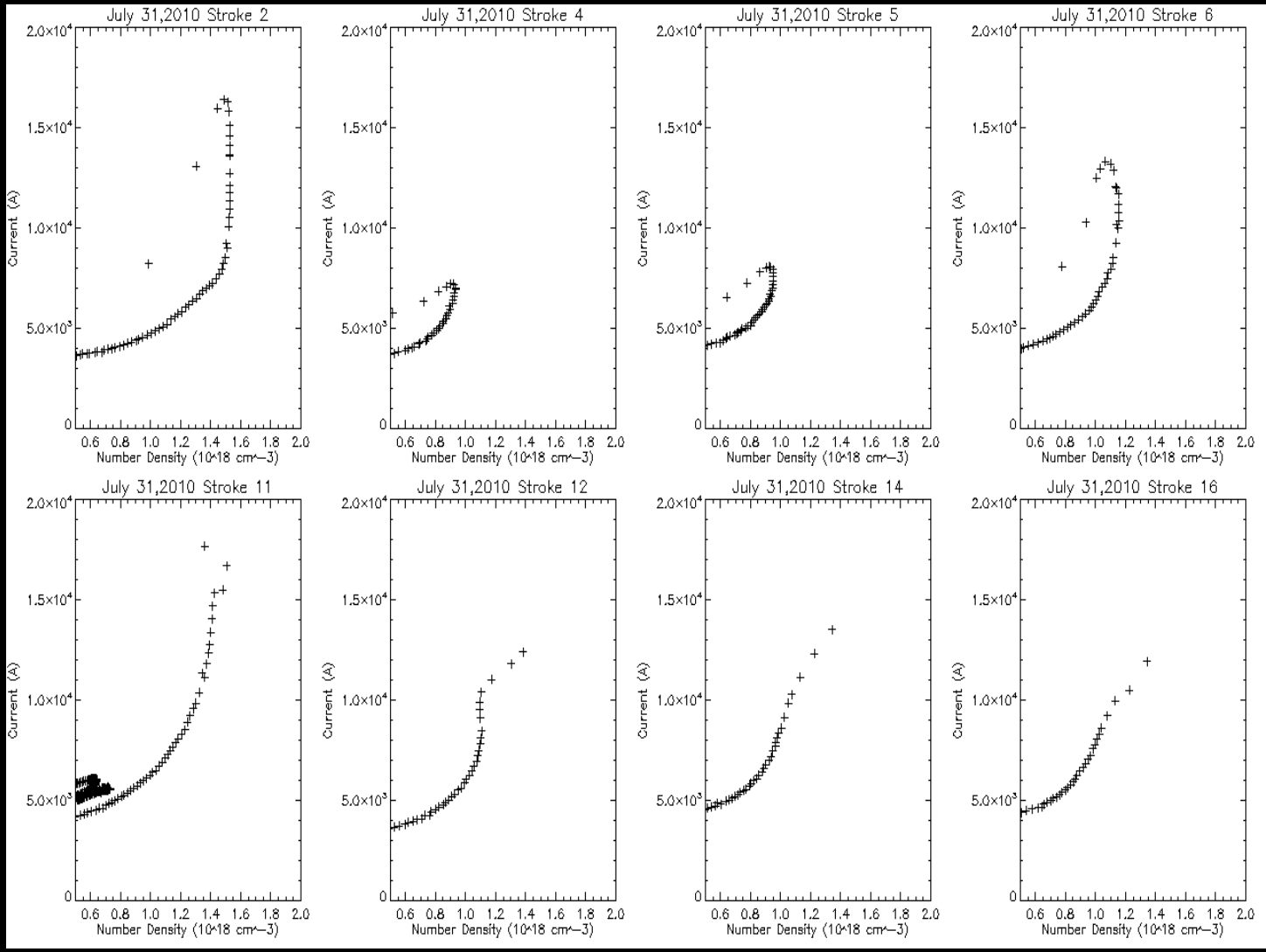

Temperatures using NII lines 5680A/5940A and OI lines 7147A/7774
Temperature (K)
4×10^4
3×10^4
2×10^4
1×10^4
0
−10
0
10
20
30
Time(μs)

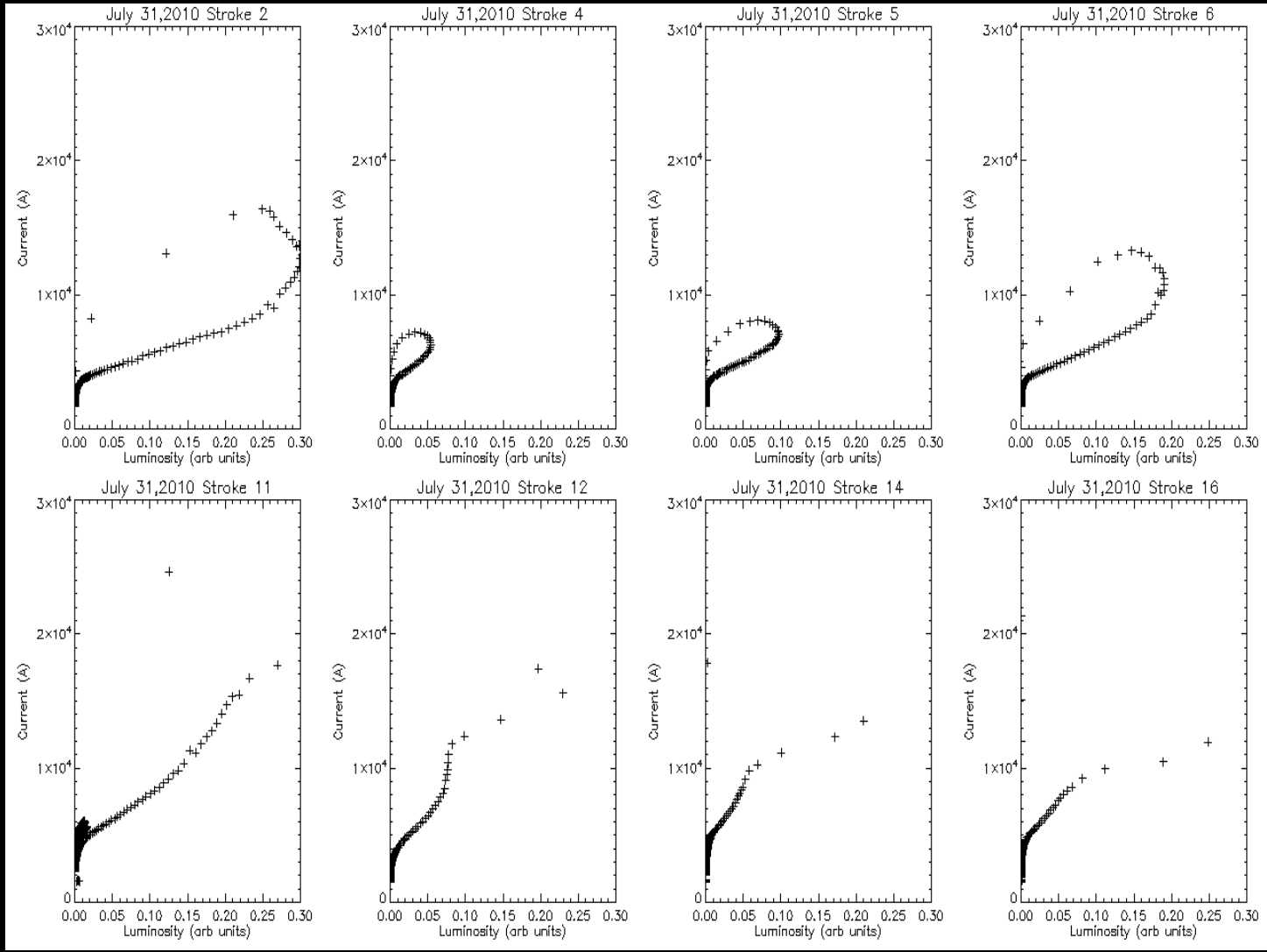

Current (Amps)
6000
5000
4000
3000
2000
1000
0
500
1000
1500
2000

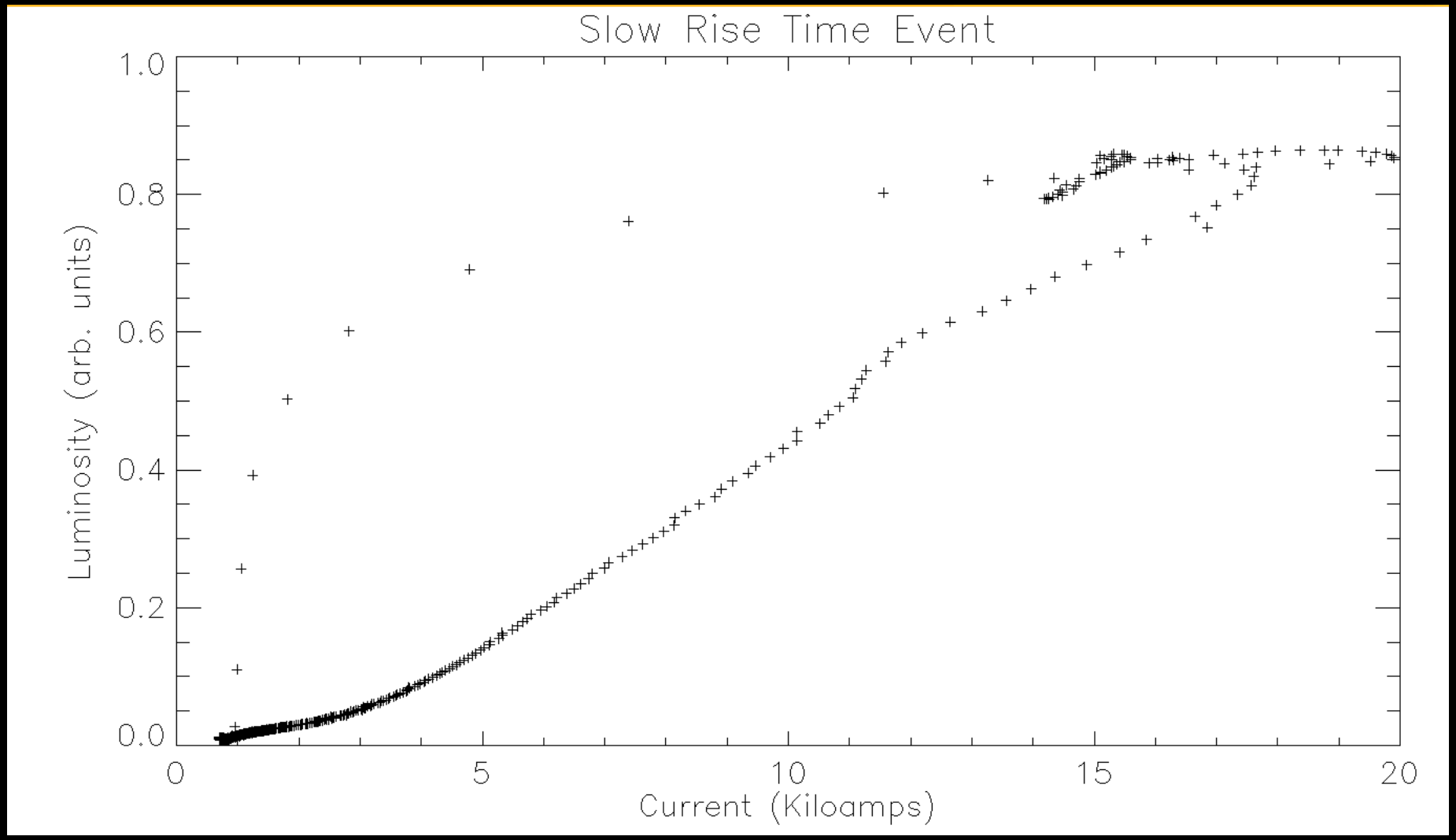

Total Luminosity
0.6
0.4
0.2
0.0
500
1000
1500
2000
Time Relative to First Return Stroke (microseconds)

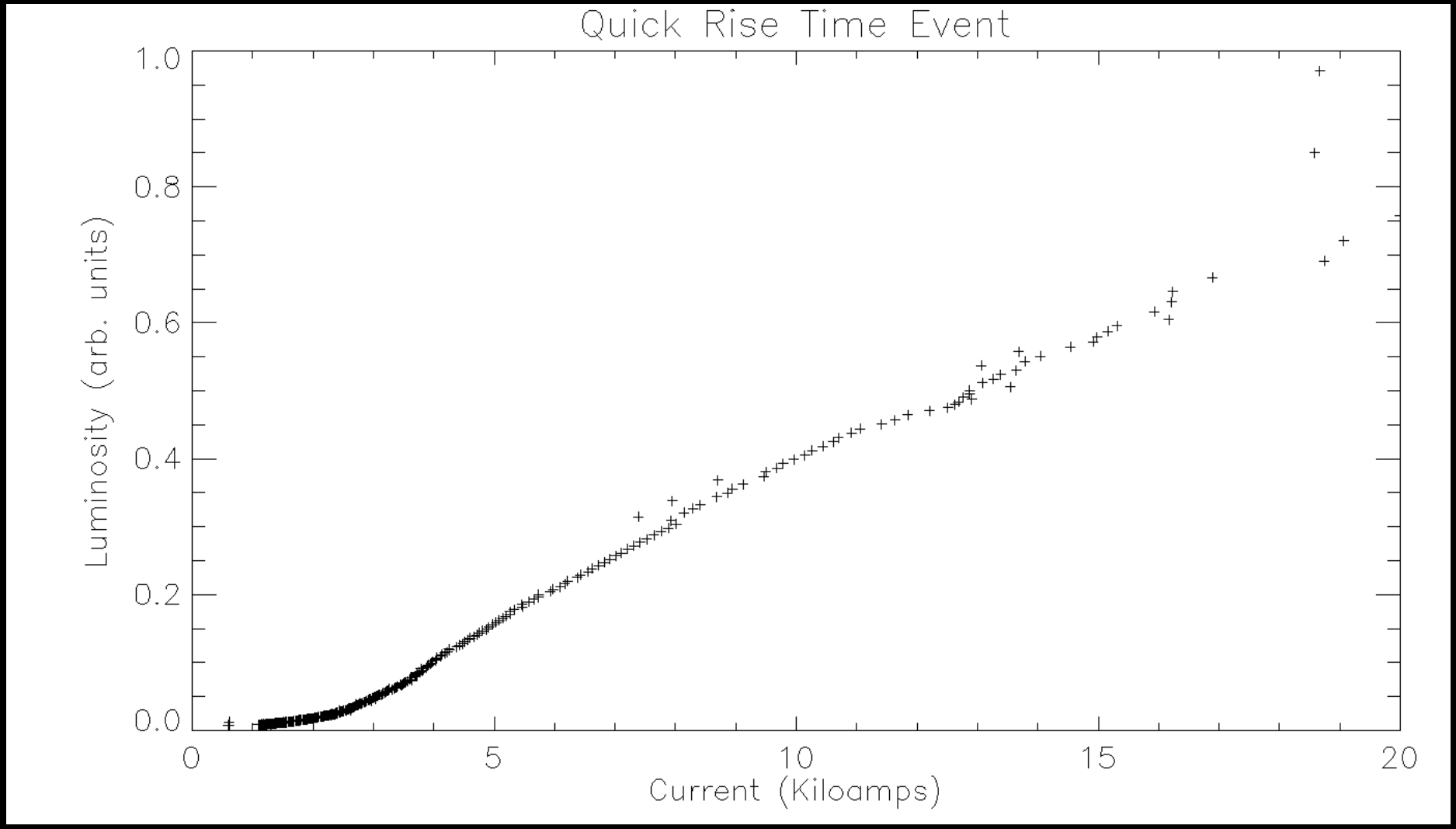

July 31,2010 Stroke 2
July 31,2010 Stroke 4
July 31,2010 Stroke 5
July 31,2010 Stroke 6
July 31,2010 Stroke 11
July 31,2010 Stroke 12
July 31,2010 Stroke 14
July 31,2010 Stroke 16
Current (A)
Time (us)


July 31,2010 Stroke 2
July 31,2010 Stroke 4
July 31,2010 Stroke 5
July 31,2010 Stroke 6
July 31,2010 Stroke 11
July 31,2010 Stroke 12
July 31,2010 Stroke 14
July 31,2010 Stroke 16
Current (A)
Temperature (K)
0
5.0×10³
1.0×10⁴
1.5×10⁴
2.0×10⁴
1×10⁴
2×10⁴
3×10⁴
4×10⁴


July 31,2010 Stroke 2
July 31,2010 Stroke 4
July 31,2010 Stroke 5
July 31,2010 Stroke 6
July 31,2010 Stroke 11
July 31,2010 Stroke 12
July 31,2010 Stroke 14
July 31,2010 Stroke 16
Current (A)
Number Density (10^18 cm^-3)
2.0×10^4
1.5×10^4
1.0×10^4
5.0×10^3
0
0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0


July 31,2010 Stroke 2
July 31,2010 Stroke 4
July 31,2010 Stroke 5
July 31,2010 Stroke 6
July 31,2010 Stroke 11
July 31,2010 Stroke 12
July 31,2010 Stroke 14
July 31,2010 Stroke 16
Current (A)
Luminosity (arb units)
0
1x10^4
2x10^4
3x10^4
0.00 0.05 0.10 0.15 0.20 0.25 0.30


Slow Rise Time Event
Luminosity (arb. units)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
Current (Kiloamps)


Quick Rise Time Event
Luminosity (arb. units)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
Current (Kiloamps)

Magnetic Confinement

Ampere's Law

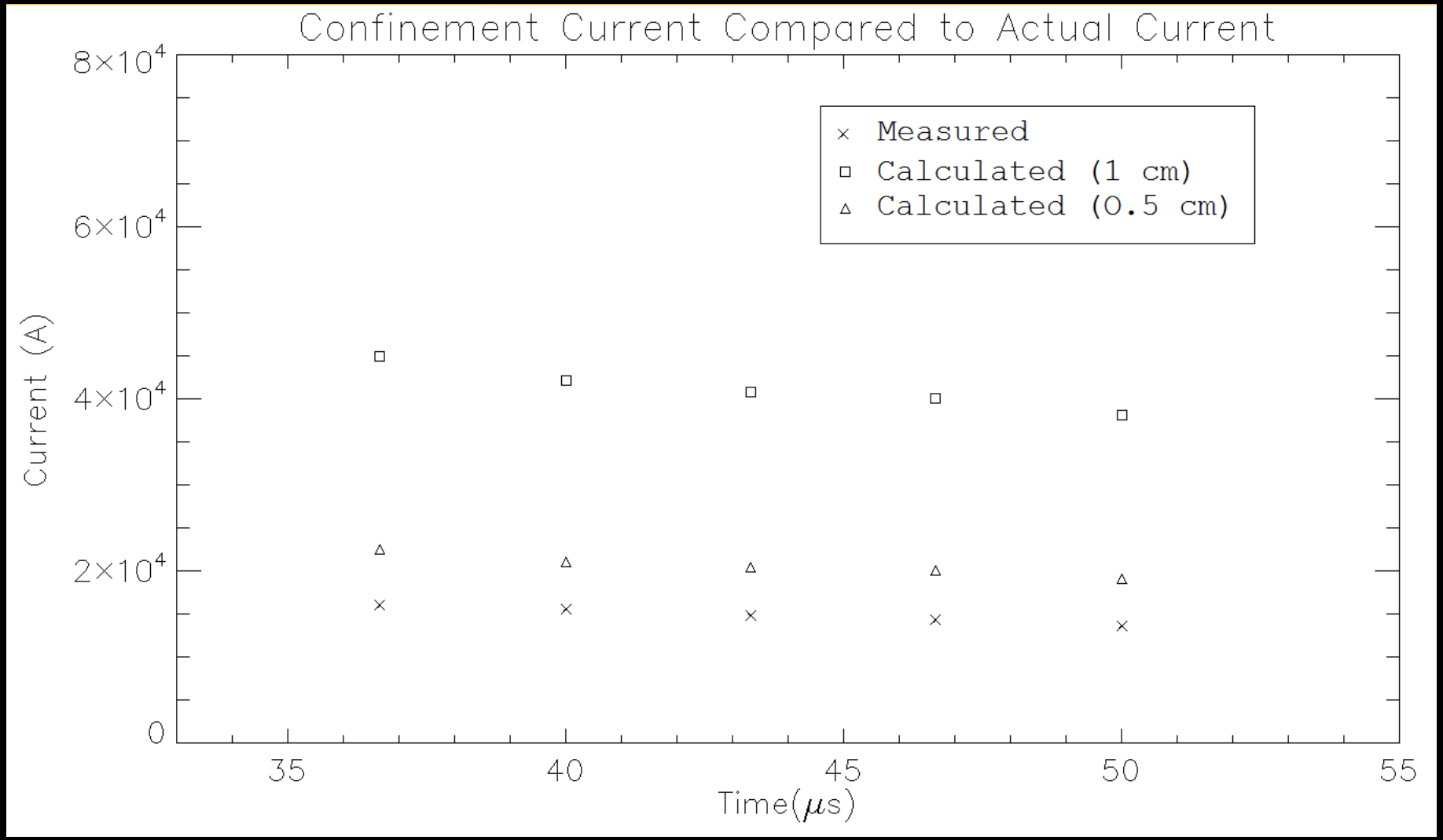
$$\nabla \times \mathbf{B} = \mu_o \mathbf{j}$$

Hydrostatic Equilibrium

$$\frac{d}{dr}\left(P + \frac{B_\theta^2}{2\mu_o} + \frac{B_z^2}{2\mu_o}\right) + \frac{B_\theta^2}{\mu_o r} = 0$$

These equations in conjunction with Ideal Gas Law yields:

$$I_{tot} = \left(\frac{8nk(T_e + T_i)}{\mu_o}\right)^{\frac{1}{2}} \pi a$$


Confinement Current Compared to Actual Current
8×10^4
6×10^4
4×10^4
2×10^4
0
Current (A)
35
40
45
50
55
Time(μs)
Measured
Calculated (1 cm)
Calculated (0.5 cm)

Conductivity

Ohm's Law

$$\mathbf{E} = \eta \mathbf{j}$$

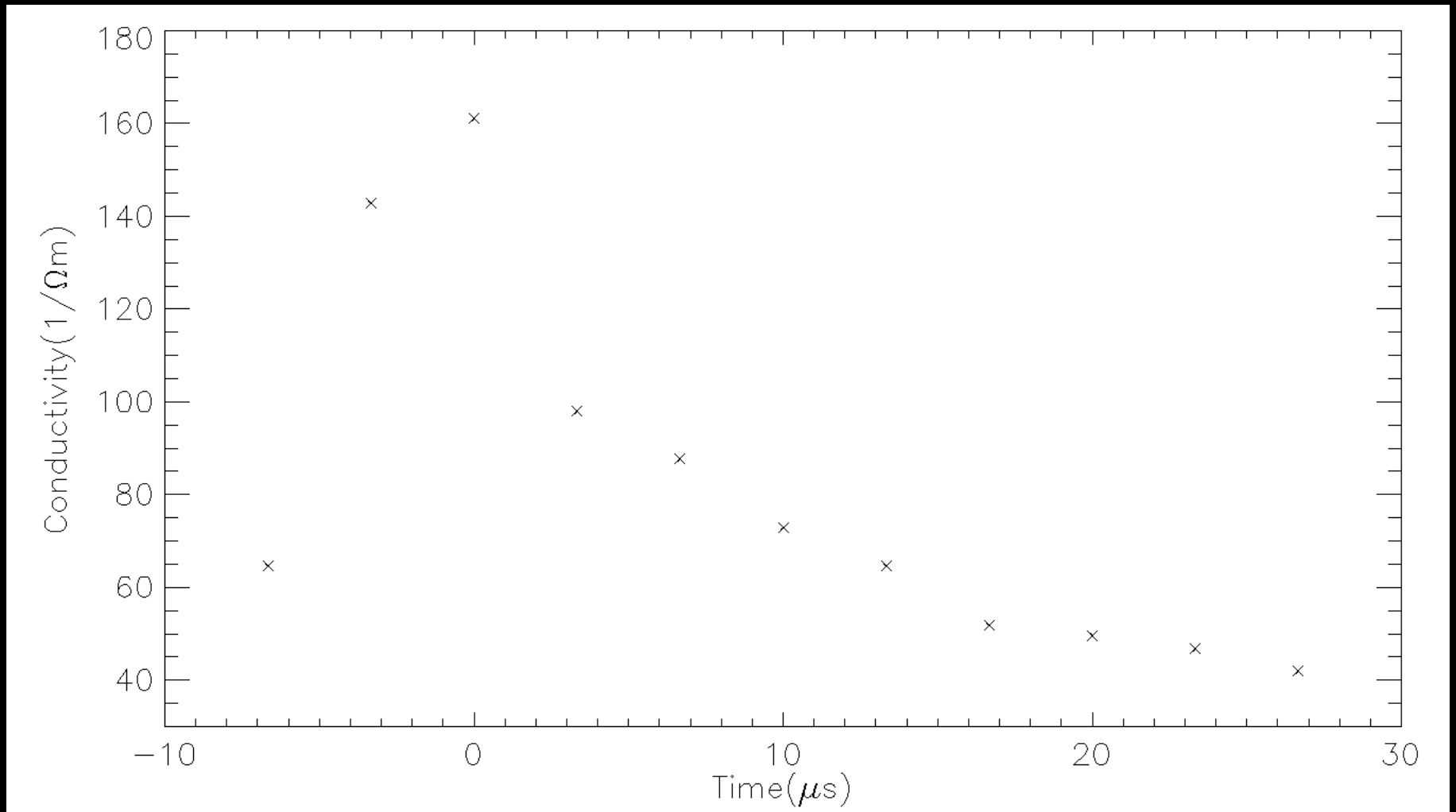
Langevin Equation

$$m_e \frac{D\mathbf{u_e}}{Dt} = -e(\mathbf{E} + \mathbf{u_e} \times \mathbf{B}) + (\mathbf{F_{coll}})$$

Using these equations along with the collisional frequency it can be shown that the conductivity is:

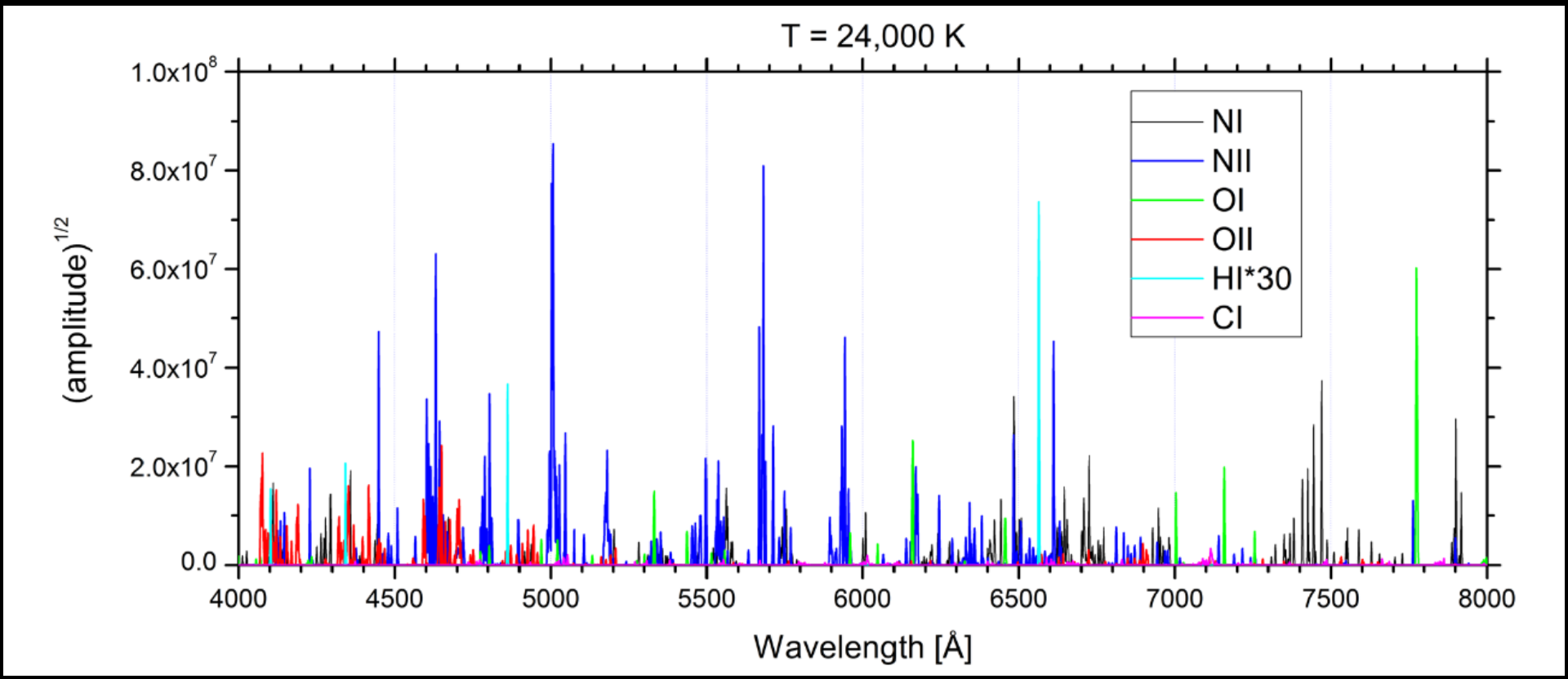
$$\eta = \frac{e^2 \ln \Lambda}{64\epsilon_o^2} \left(\frac{m\pi}{2}\right)^{\frac{1}{2}} (kT)^{-\frac{3}{2}} \frac{n_i}{n_e}$$

Λ is a function of Temperature and weakly number density


180
160
140
120
100
80
60
40
Conductivity(1/Ωm)
−10
0
10
20
30
Time(μs)

High Speed Spectroscopy – what next?

- Continue to probe the lightning physics
  - time resolved full gas dynamical model
  - measure peak temperature, density and luminosity
- Using synthetic spectra, identify spectral anomalies



High Speed Spectroscopy – what next?

  - Why is H alpha so strong
  - Is Local Thermal Dynamic Equilibrium always in play?
  - Does the axial electric filed affect electron energy and hence the spectra?
- Determine the physical characteristics of the leader including the electric field in front of the leader
- Determine the physical characteristics of intercloud lightning
  - How do the energetics compare?
  - what is the channel diameter, temperature and density?
- Measure the spectra of the cooling channel
  - identify molecular species as it cools – Nox
- Remotely detect inner shell processes
  - Auger emissions
  - May help determine when high energy electrons are being emitted inside the cloud
- Remotely estimate lightning currents as a function of time?
  - Use in conjunction with the HAMMA array to intercompare estimates
  - Calculate total lighting energetics
  - Implications for GLM