Sun as a Star Data from RV Instruments

Debi Prasad Choudhary

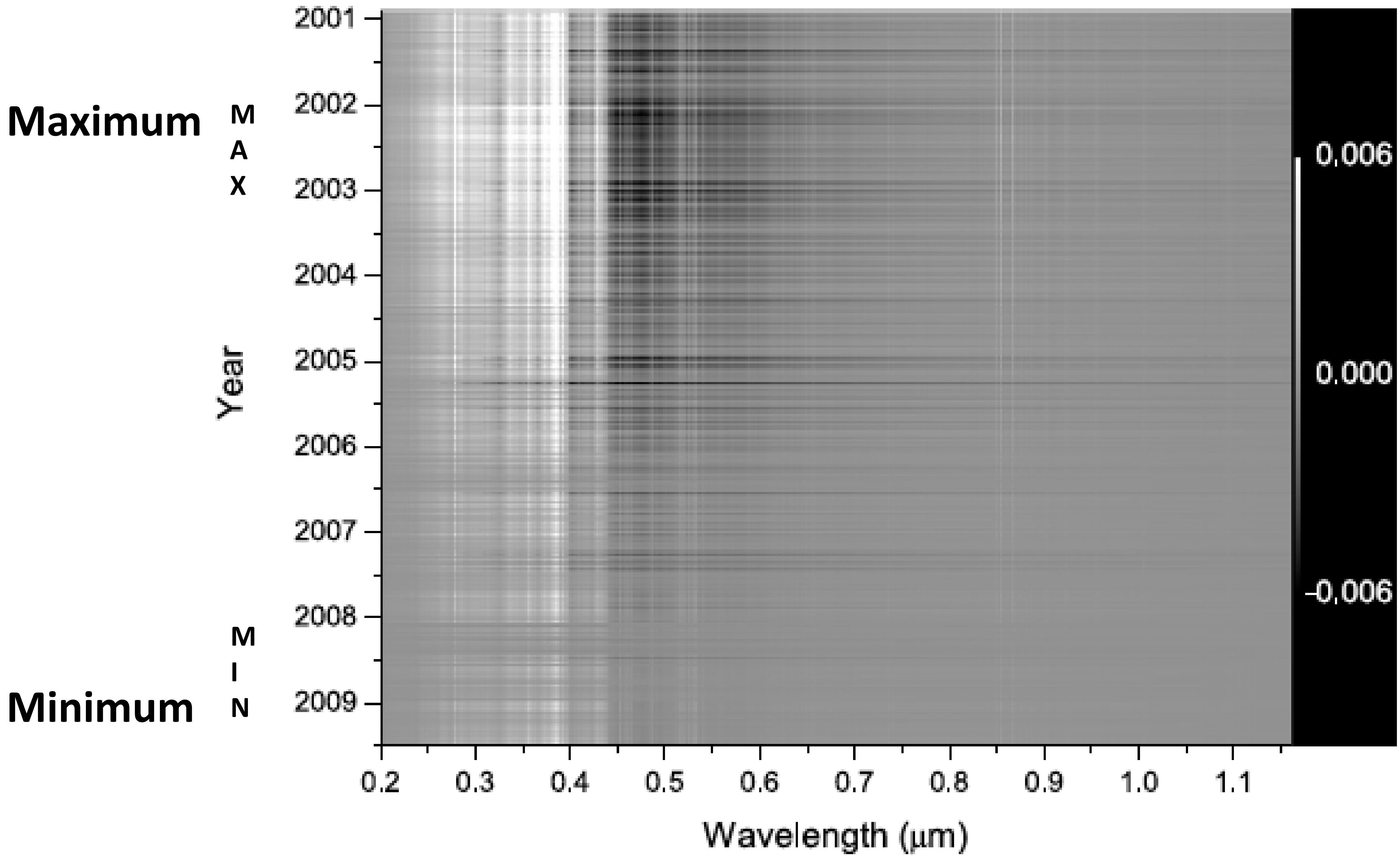
Department of Physics and Astronomy

California State University Northridge

Modeling full-disk Solar Spectral Irradiance:

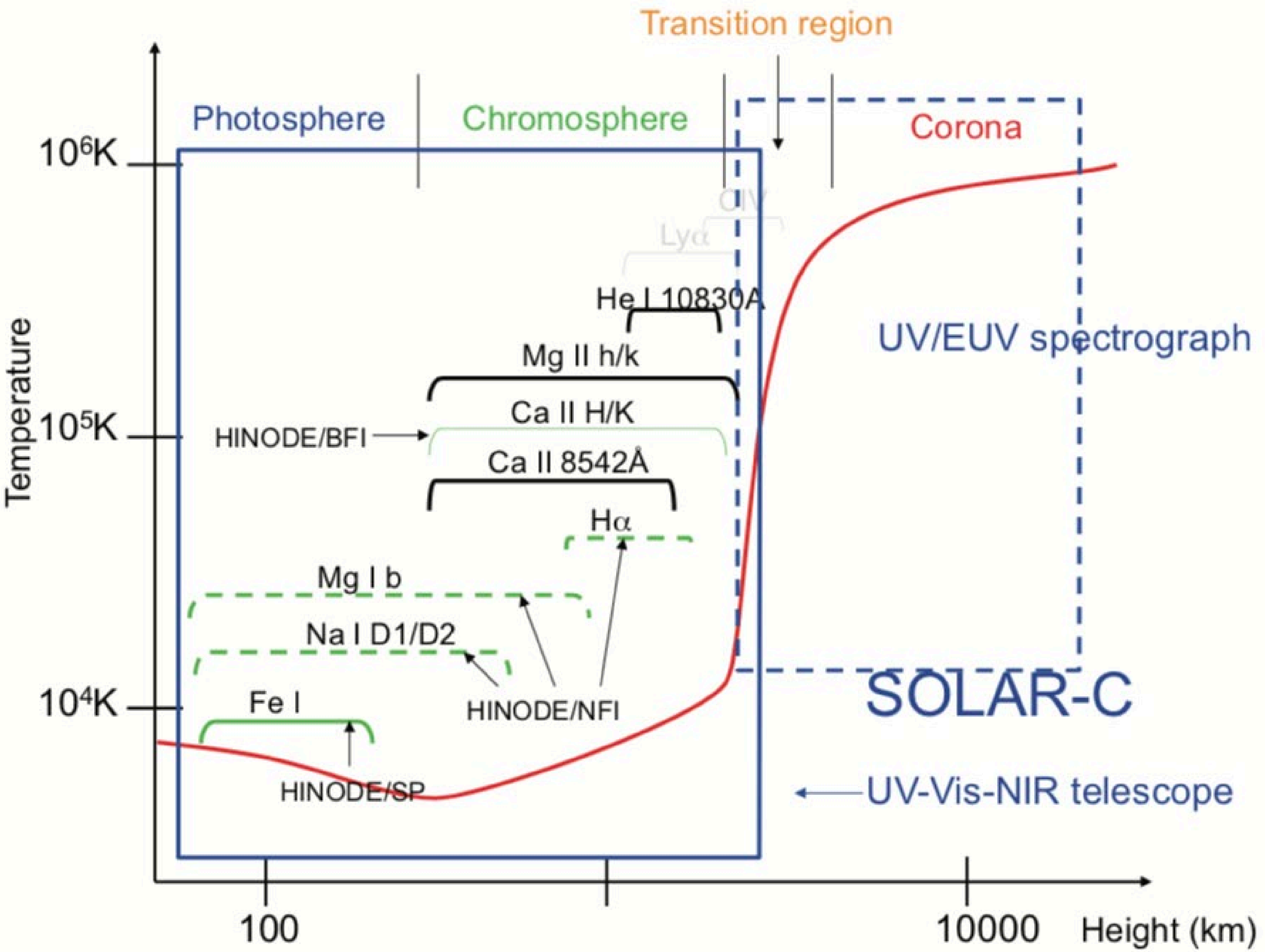
We plan to use the daily spectra of sun-as-a-star and compare them with synthetic spectra constructed using the combination of spectra of various solar structures on photometric full disk images proportional to their coverage.

The goal of this task is to measure the line blanketing effect on a daily basis using the spectra of the Sun-as-a-star.



Maximum
MAX
Minimum
MIN
Year
2001
2002
2003
2004
2005
2006
2007
2008
2009
0,006
0.000
-0,006
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Wavelength (μm)

Line Formation



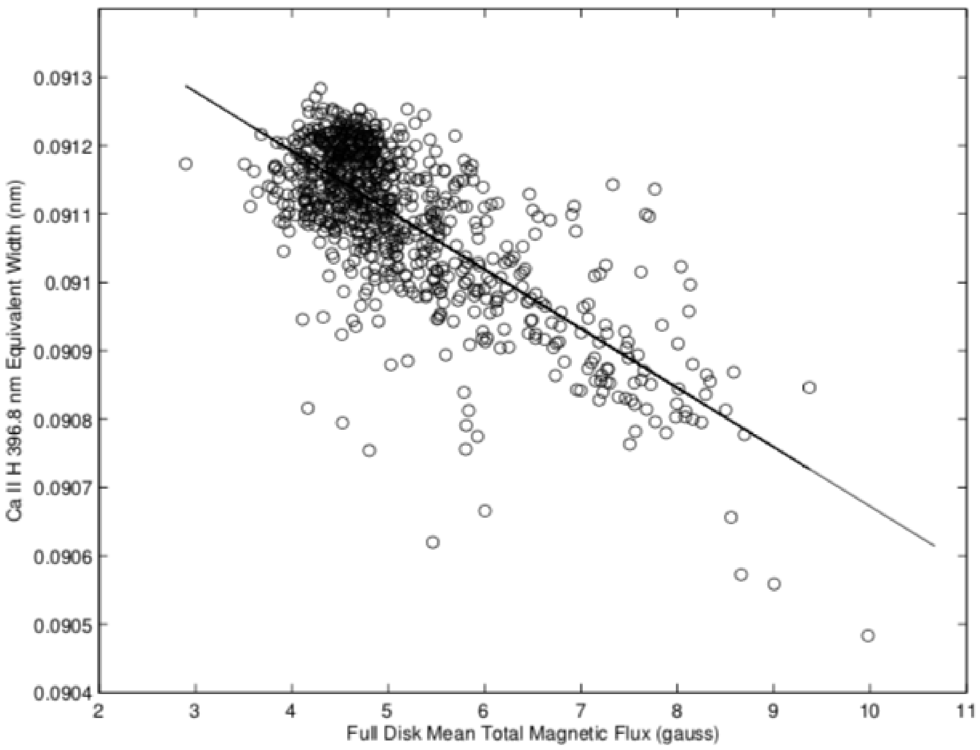
Motivation

Identification of Physical Processes for solar brightness variation.

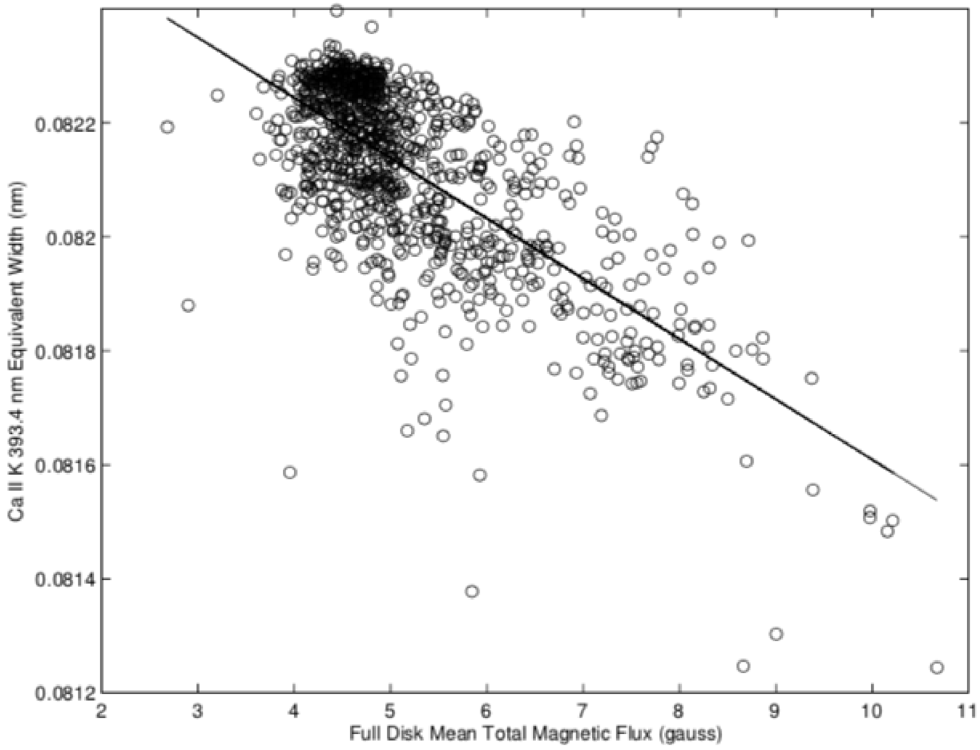
- Deep photospheric lines show little or no variation with solar cycle unlike the chromospheric lines (White, Livingston, Wallace, 1987, Livingston and Wallace, 2003).
- The variation in Fraunhoffer lines define the amplitude of the solar brightness variability (Shapiro et al 2015).

- Solar cycle variation of Solar Spectral Irradiance is the consequence of multiple active region outbursts (Woods et al, 2015).
- Continuum variations only contribute negligibly compared to spectral-line to the total irradiance variations on solar-cycle time scales (Unruh et al, 1999, AA, 345, 635).
- Complex relationship with magnetic field was found and areas of strong magnetic field can appear either dark or bright, depending on wavelength (Norris et al, 2017).

Magnetic field dependence of Ca H and K EW.

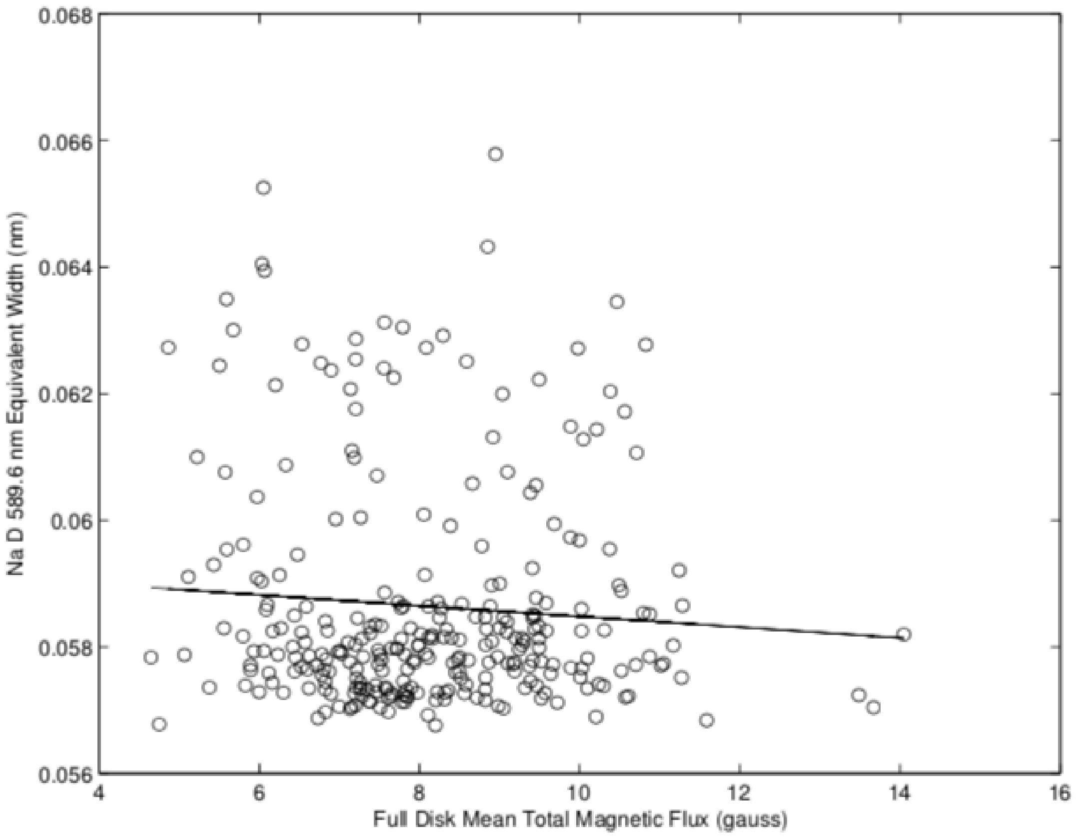


(e) Ca II H EW vs FDMTMF

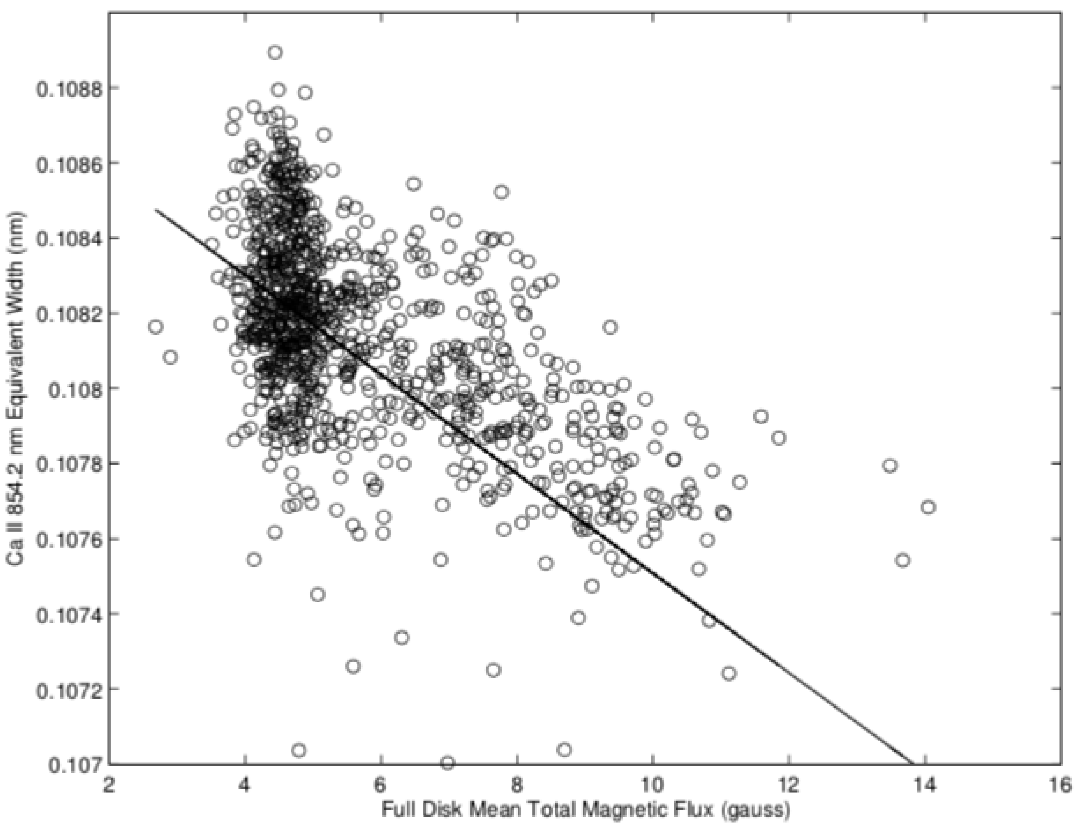


(f) Ca II K vs FDMTMF

Na 589.0 nm and Ca II 854.2 nm EW

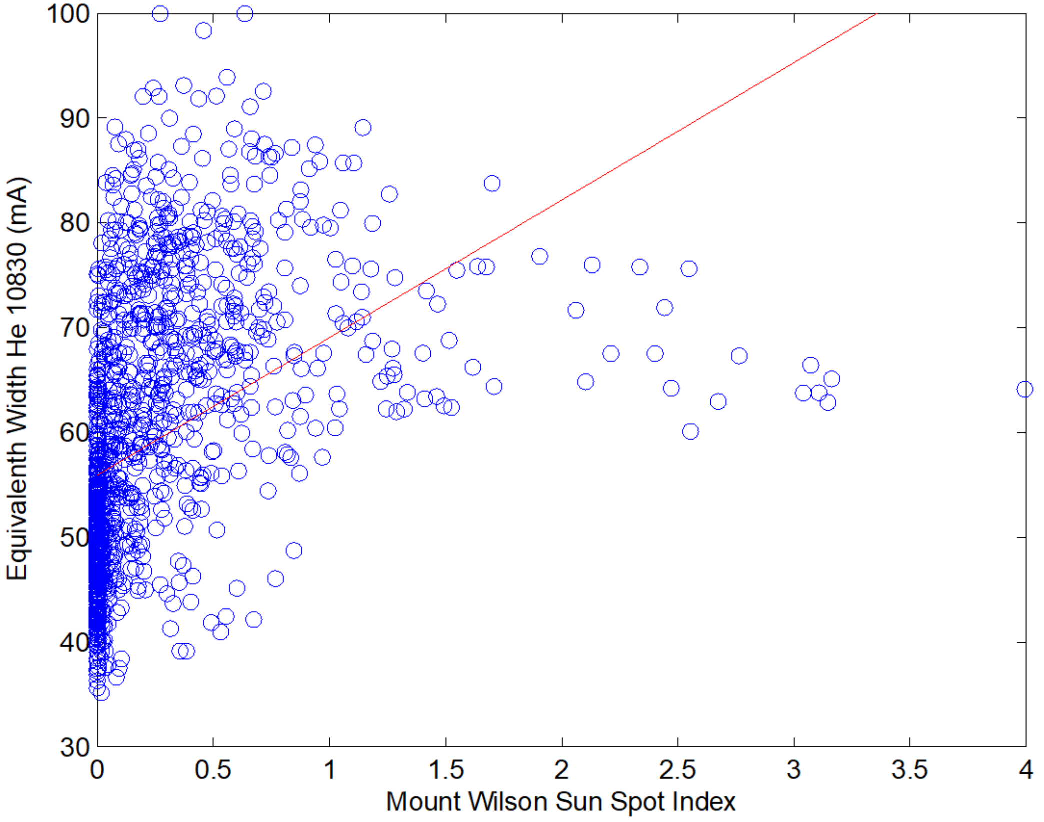


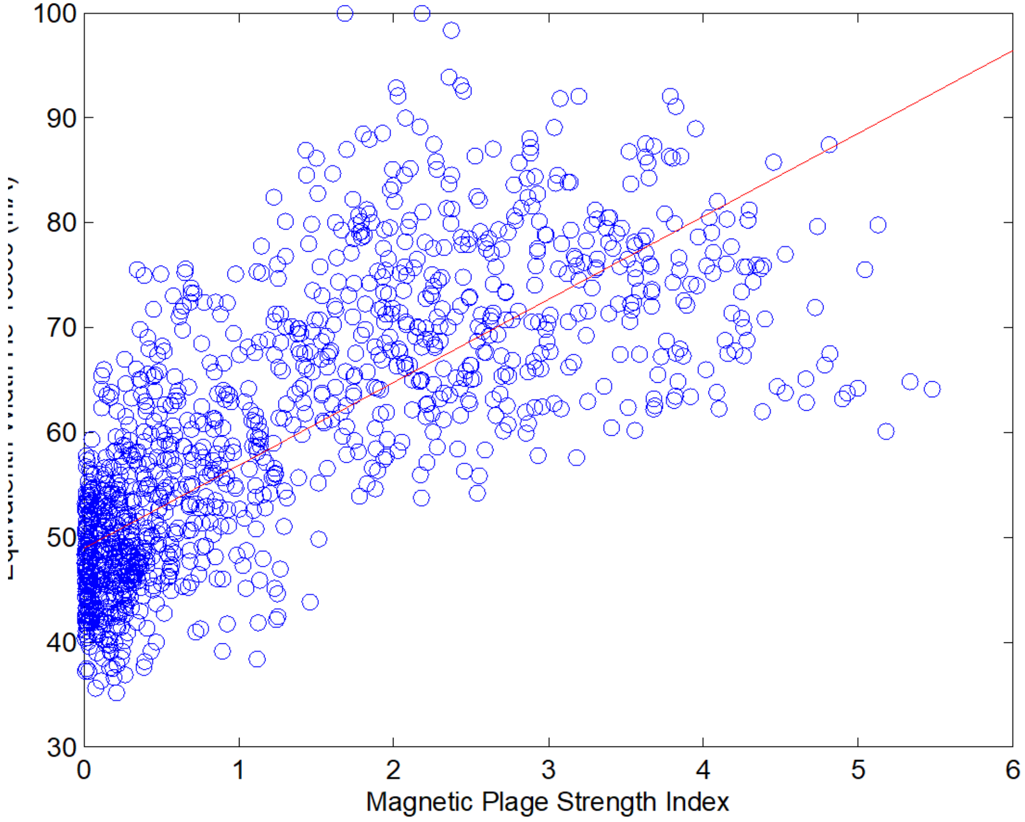
(c) Na D I EW vs FDMTMF



(d) Ca II EW vs FDMTMF

Magnetic field Vs He I 1083 nm EW.





Summary

- EW decrease with full disk mean total magnetic flux (FDMF) for all chromospheric lines except HeI 1083.0 nm. The chromospheric lines become brighter.
- The slope of FDMF versus chromospheric lines are different for the lines forming at different heights. (Fraunhoffer lines originating in deep photosphere are unchanged through the solar cycle.)
- Understanding the role of magnetic field in line-formation mechanism of chromospheric lines will help understand the SSI variability.

Instruments

Telescope	Spectral Range	Resolution	Cadance	
Wiyn 3.5 m + *NEID*	380-930 nm	110,000	300 spectra a day	
ESO 3.6 m + HARPS	380 – 690 nm	115, 000		72 echelle orders
Discovery Channel 4.3 m + EXPRES	380 – 680 nm	150, 000		
Large Binocular Telescope 11 m + PEPSI	389 – 914 nm	270, 000	time-series of 996 high-cadence spectra	
Keck Planet Finder **10 m Keck I** telescope	445-870 nm	90,000		green channel (445nm to 600nm) and red channel (600nm to 870nm). A supplementary UV spectrometer (385–405nm)

NEID Characteristics

- Echelle design with prism cross-disperser
- Continuous broadband wavelength coverage (380-930 nm)
- 9K x 9K e2v CCD with 10 micron pixels
- Choice of two science fibers for two resolution modes: One is the high resolution (HR) mode (R>110,000) for bright targets (V<12). The other, a high-efficiency (HE) mode (R~60,000), is designed for fainter stars or poor observing conditions.
- Spectrograph throughput is >40% at 500 nm for a mean system throughput of 5.6% over the full bandpass in HR mode
- Chromatic exposure meter gathers a time series of low-resolution spectra in parallel to each science spectrum, enabling barycentric corrections to <1 cm/s
- Ultra-precise wavelength calibration via multiple sources, including a laser frequency comb
- Additional simultaneous calibration via the laser frequency comb can be requested (a Fabry-Perot etalon will be used as a backup if the LFC is not available on a given night, but cannot be requested)

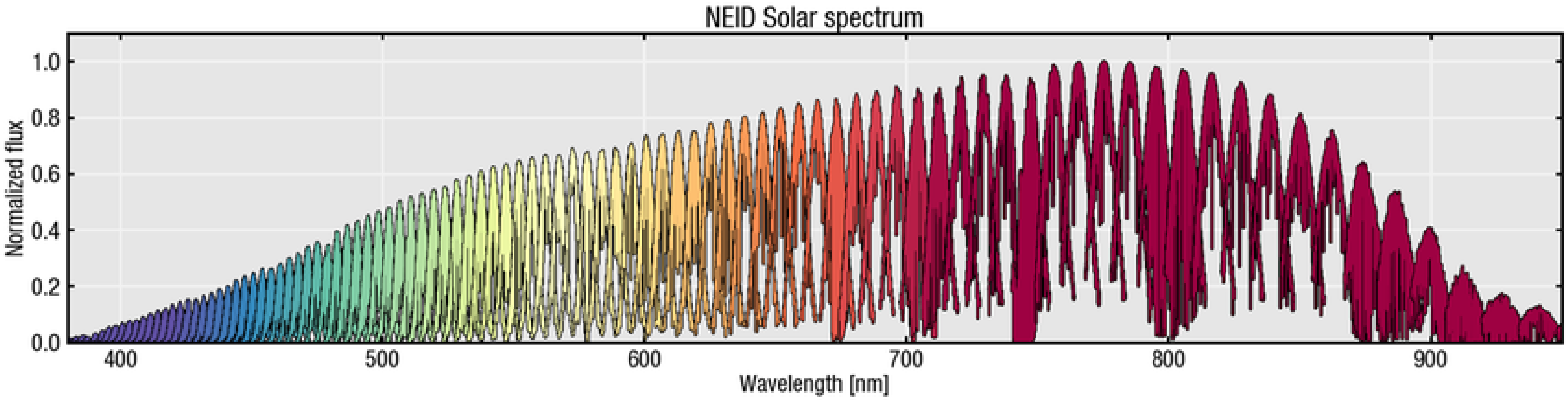
Data Products – become available after 18 months

- All data taken with NEID are processed through the NEID data reduction pipeline run daily at NExScI (https://neid.ipac.caltech.edu/search.php).

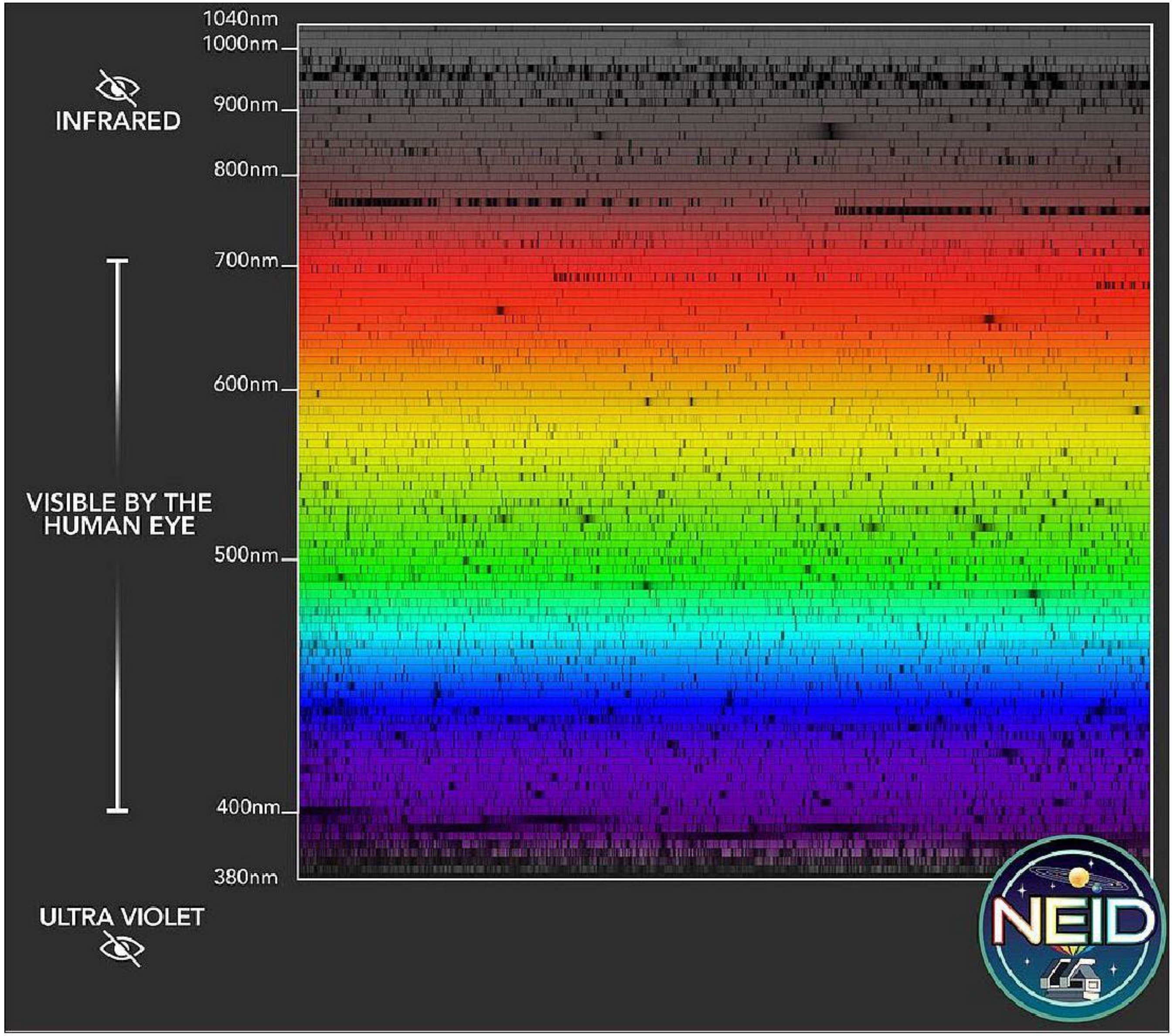
The following data products are available via the NEID archive at ipac:

- Raw 2D echellogram
- Representative guider camera image
- Representative coherent fiber bundle flux data stream
- Extracted, 1D wavelength calibrated spectra and uncertainties for the science, sky, and calibration fiber
- Representative telluric absorption model
- Representative sky emission model
- Cross-correlation functions by order and barycentric corrected RVs
- Parameterized activity indicators

A typical 1D solar spectrum taken with NEID and reduced by the NEID DRP, showing the overall instrumental response and blaze response.



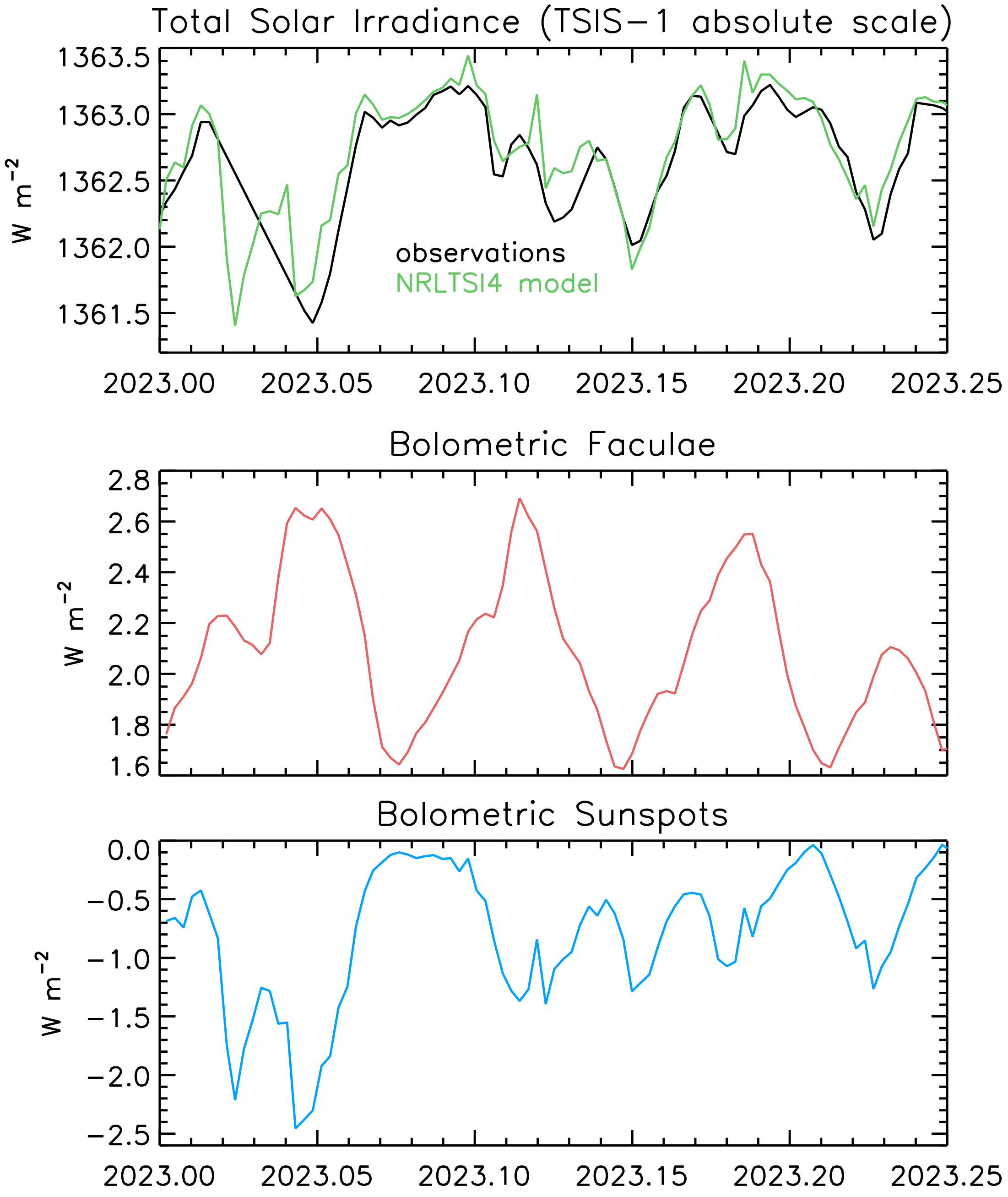
A typical Spectrum



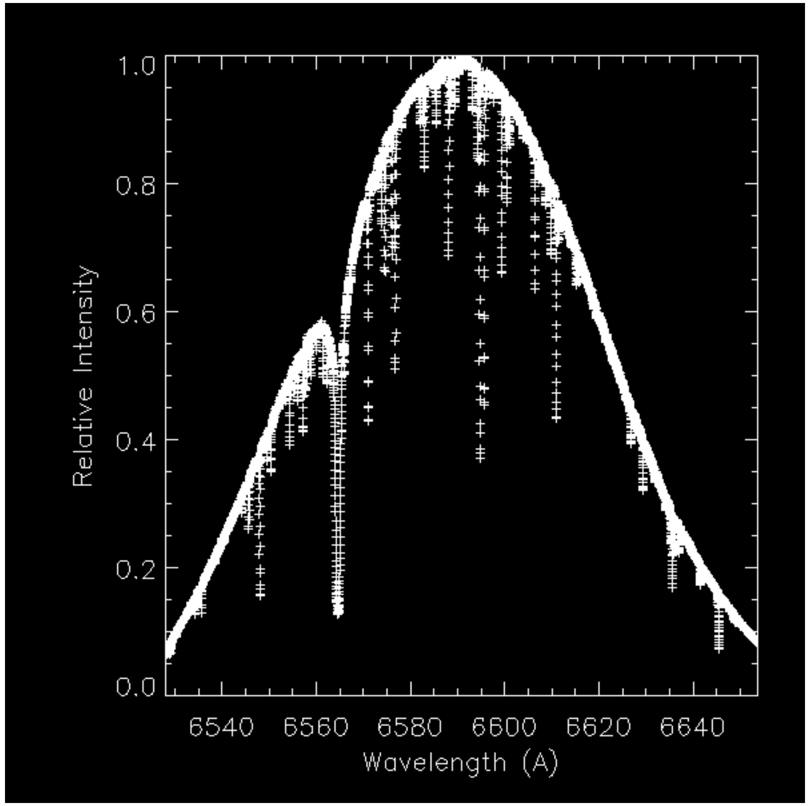
Spectral Lines

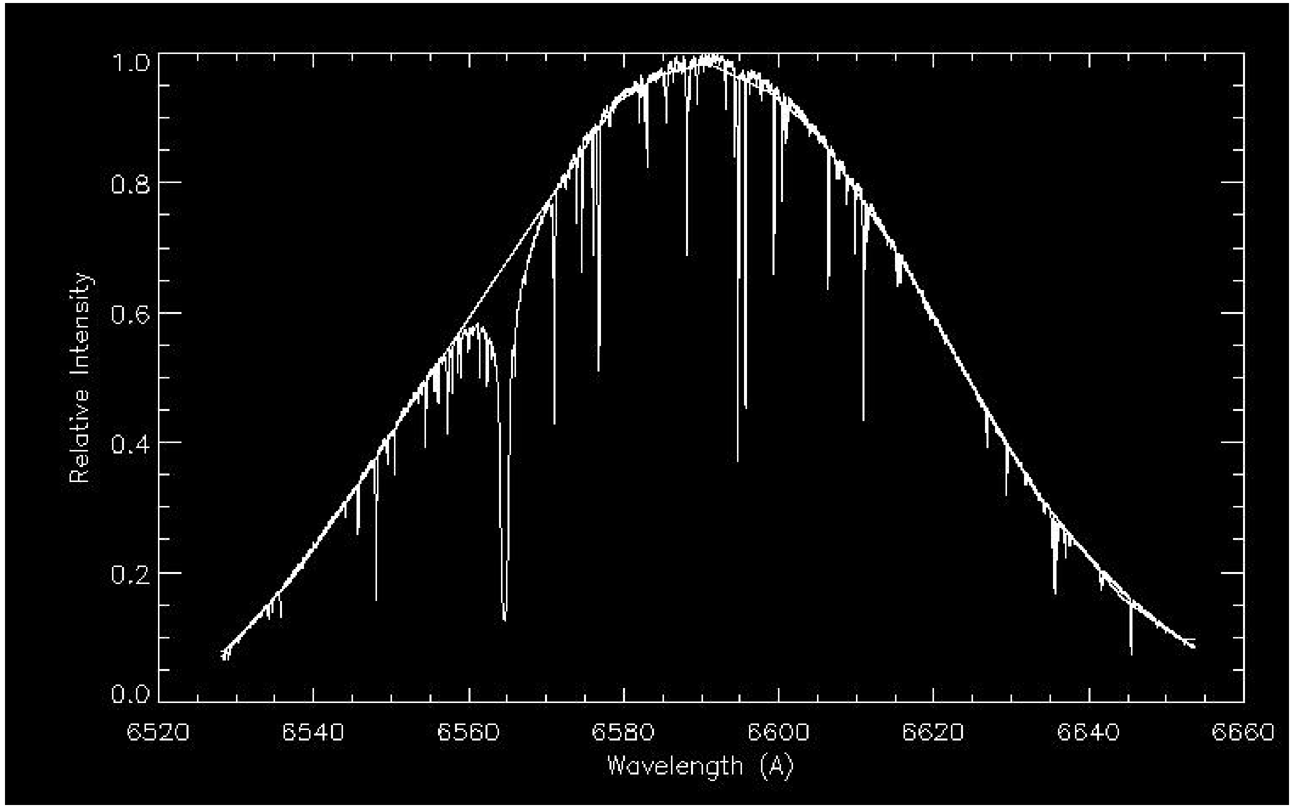
Wavelength (nm)	Spectra	Order NEID	Equivalent Width (nm)	Region	Height (km)	Temperature
393.36	Ca II K	17	2	Chromosphere	600-1500	
396.85	Ca II H	19	1.5	Chromosphere	1000-2000	
517.27	Mg I b2	55	0.075	Low Chromosphere		
518.36	Mg I b1	55	0.025	Photosphere		
537.96	Fe I	59	0.0079	Mid Photosphere		
557.61	Fe I	63	0.0025	Photosphere		
589.0	Na I D2	69		Upper photosphere-lower chromosphere		
589.59	Na I D1	69	0.075	Upper photosphere-lower chromosphere		
656.28	H alpha	80	0.41	Chromosphere	1250-1700	
849.8, 854.21	Ca I	101	0.13, 0.37	lower chromosphere		
866.2	Ca I	102	0.27	lower chromosphere		

Test Data: January 1 to March 20, 2023

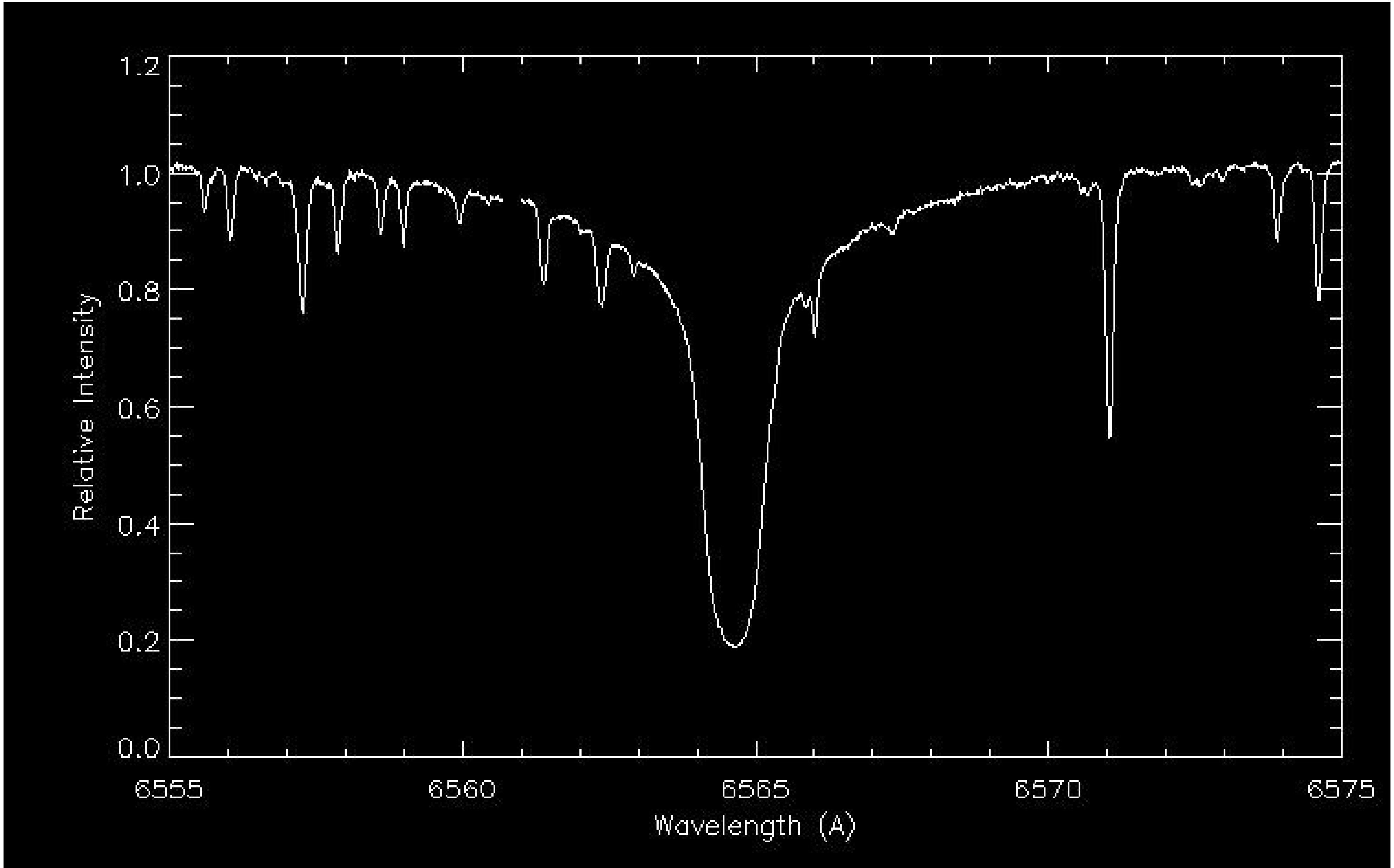


Halpha (Order)

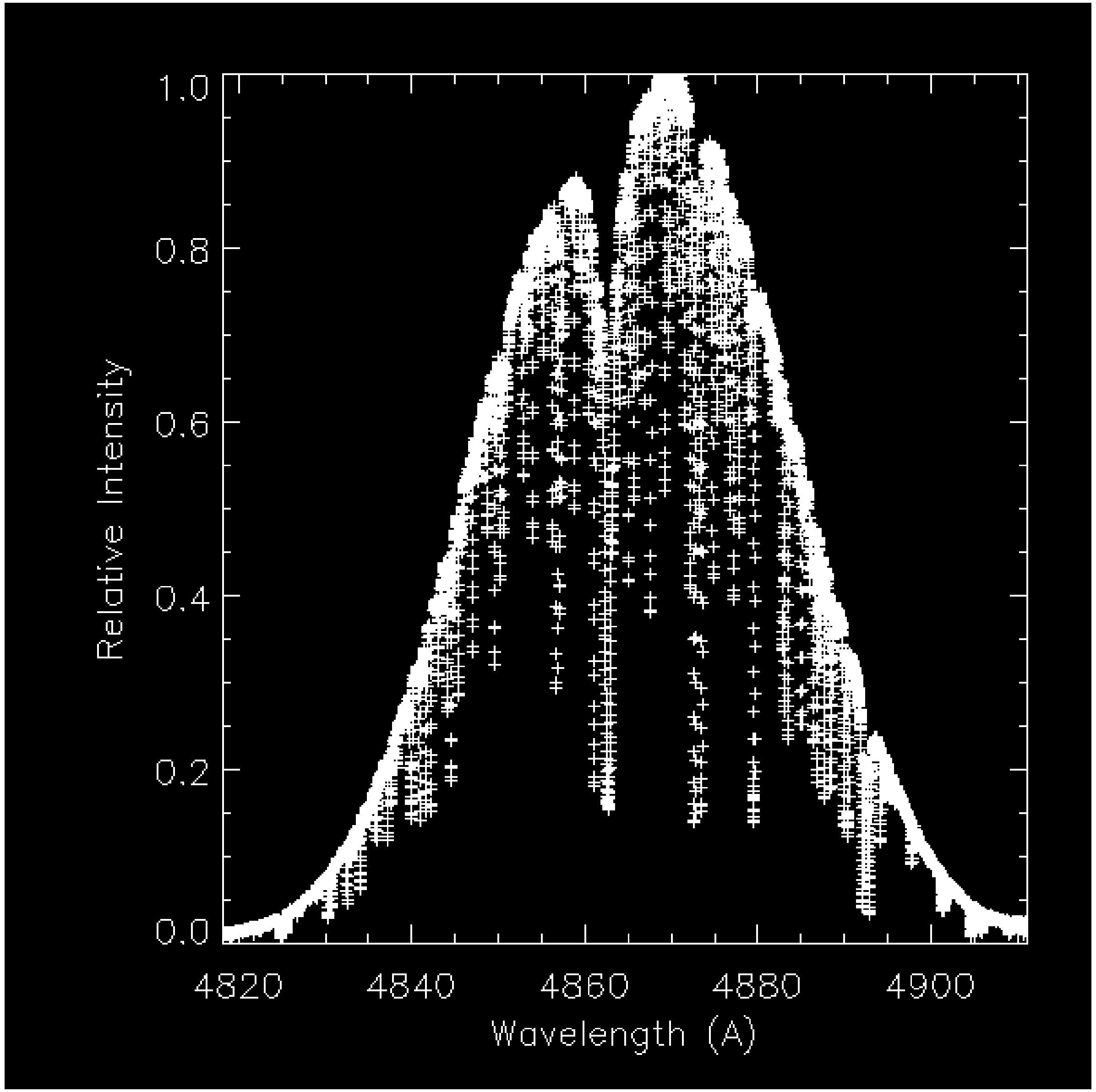


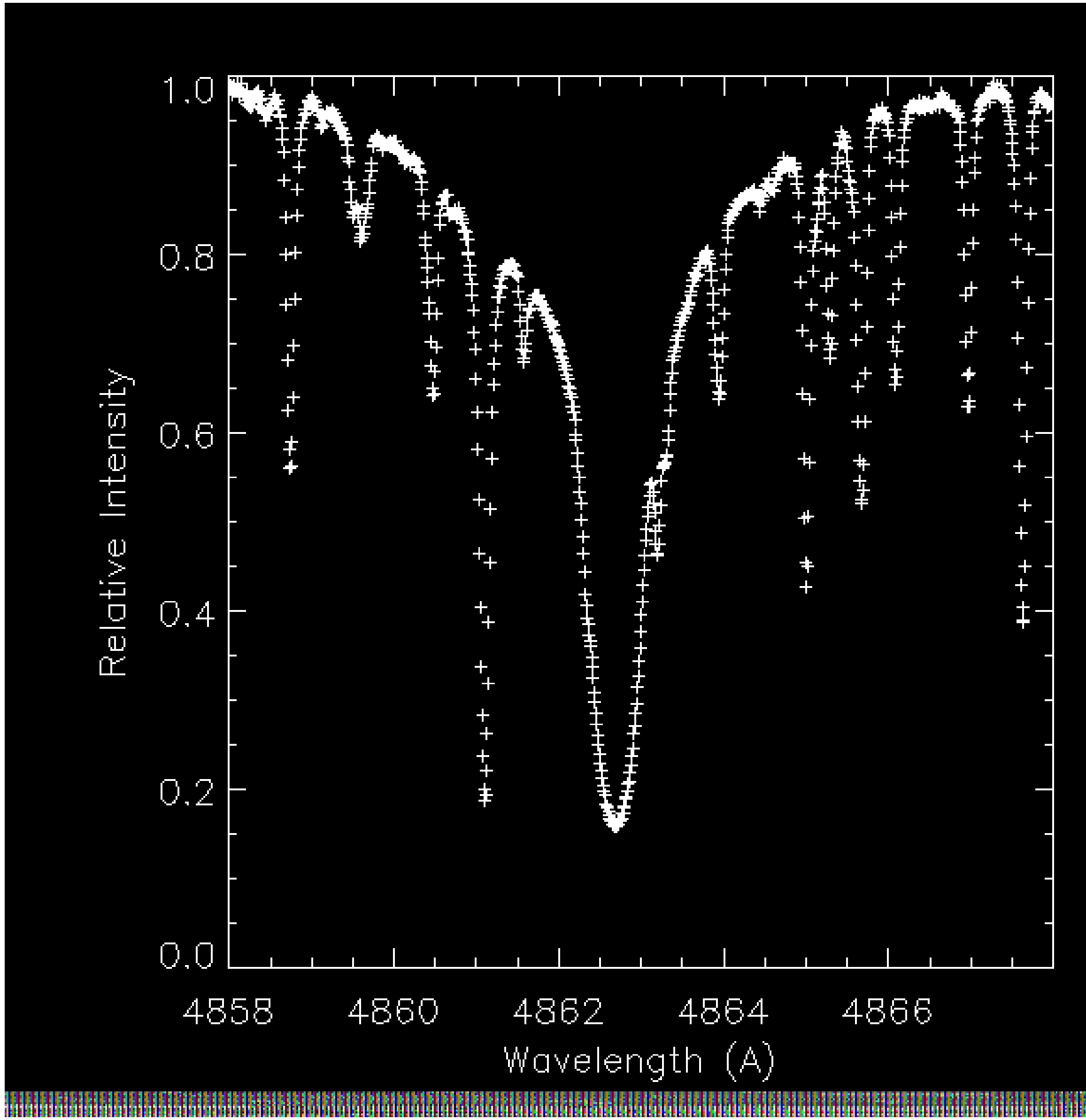


Halpha Spectra

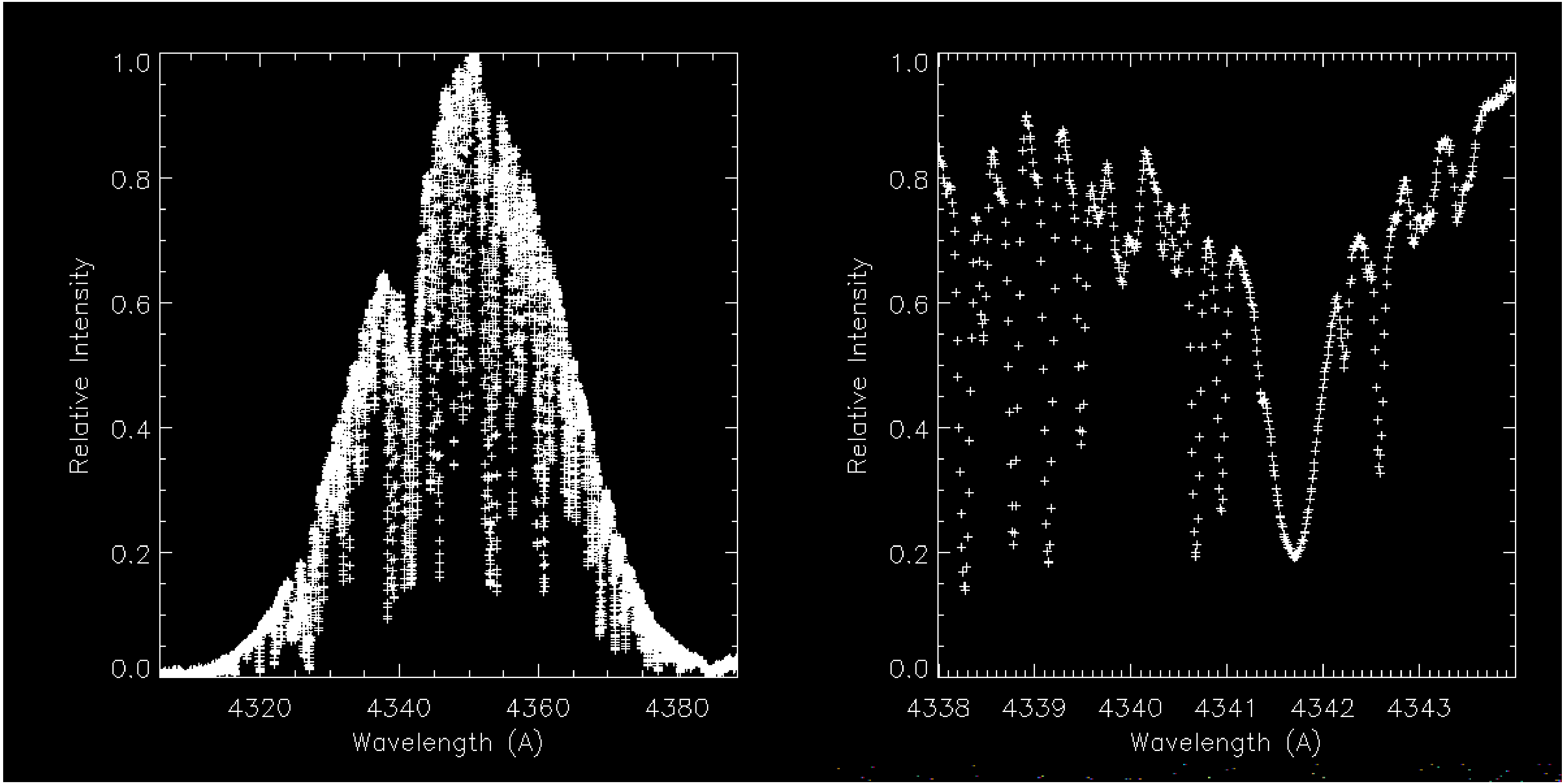


HBeta


1.0
0.8
0.6
0.4
0.2
0.0
Relative Intensity
4820
4840
4860
4880
4900
Wavelength (A)

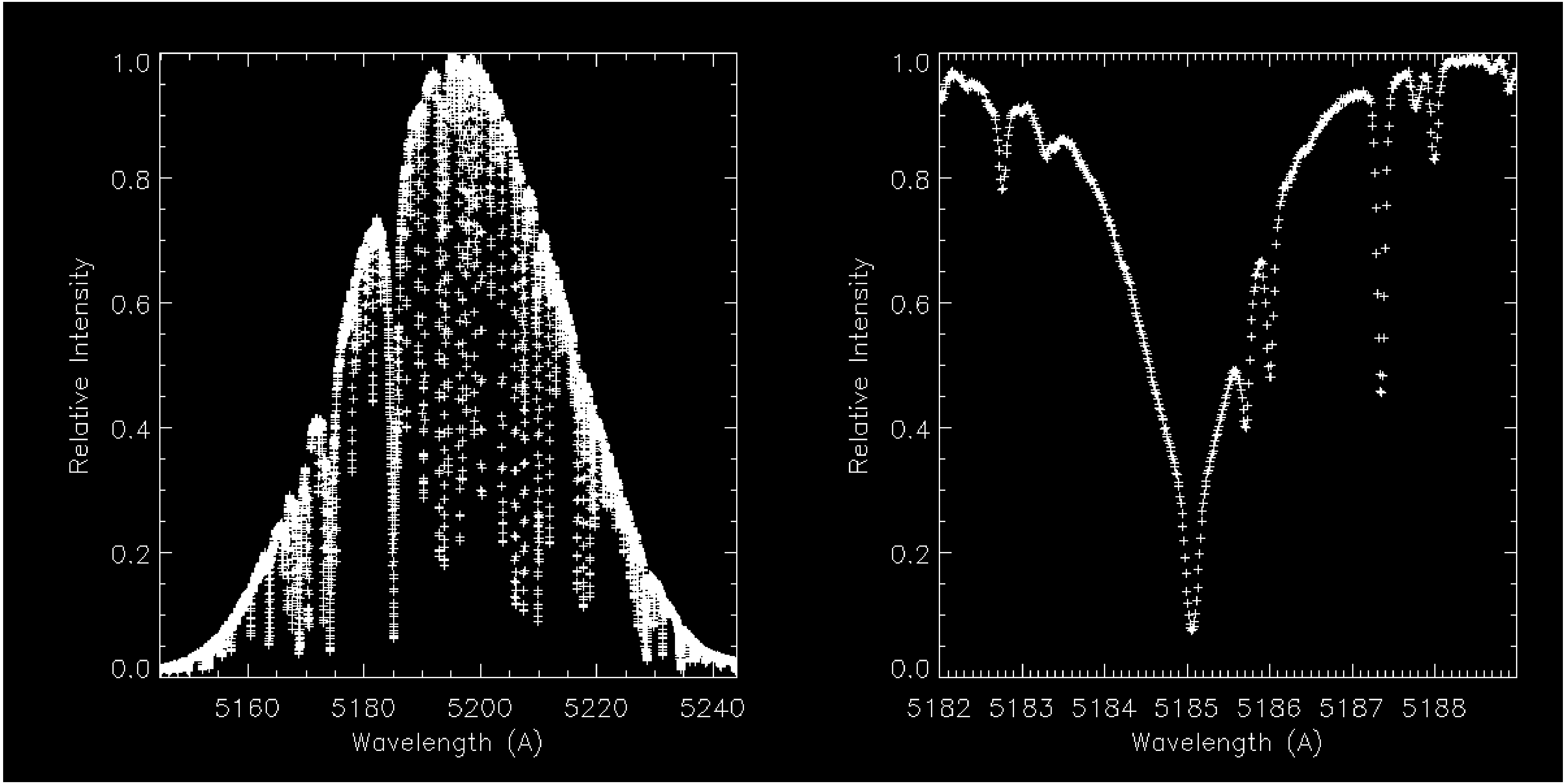

1.0
0.8
0.6
0.4
0.2
0.0
Relative Intensity
4858
4860
4862
4864
4866
Wavelength (A)

HGamma



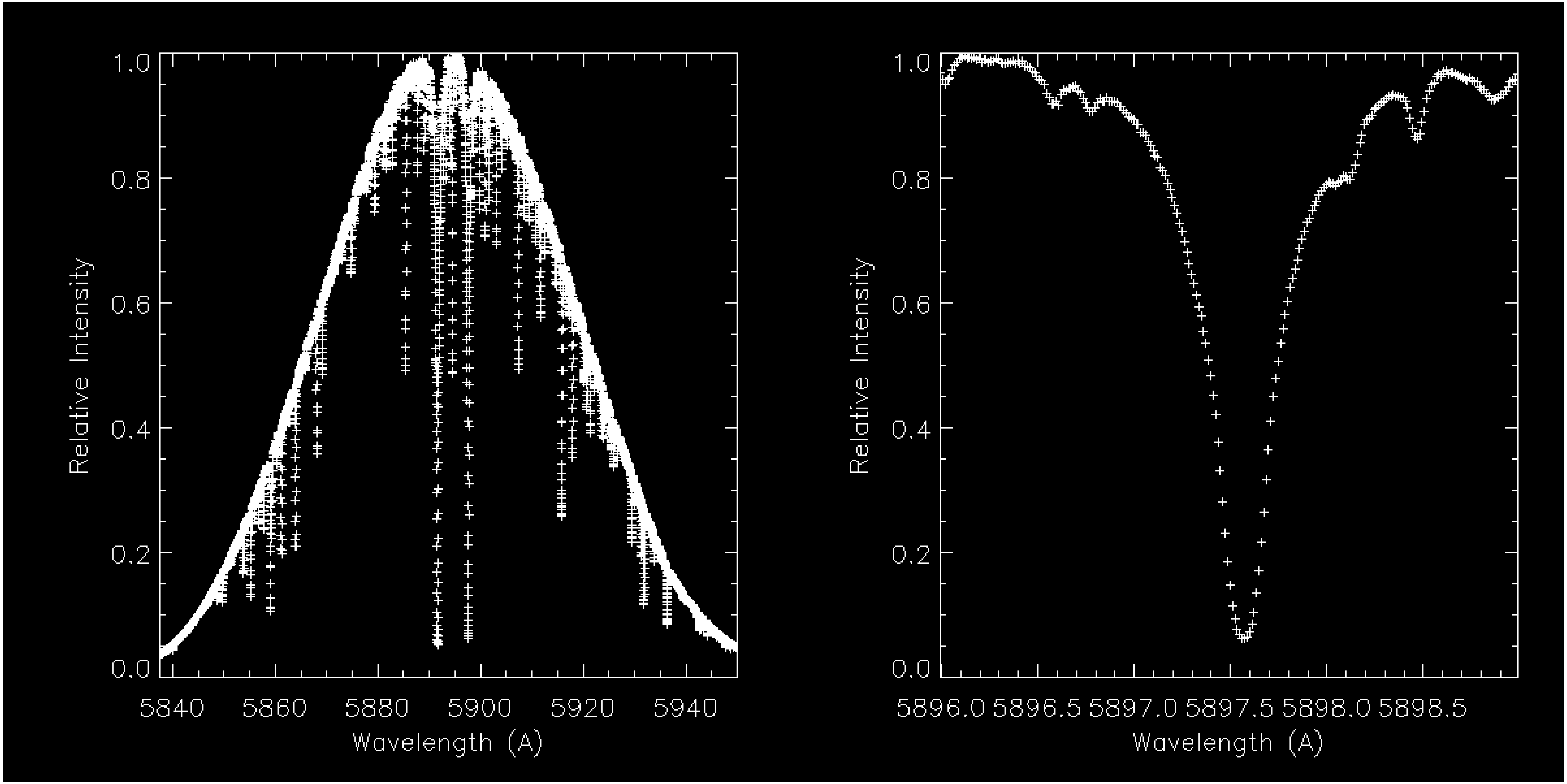
1.0
0.8
0.6
0.4
0.2
0.0
Relative Intensity
4320
4340
4360
4380
Wavelength (A)
1.0
0.8
0.6
0.4
0.2
0.0
Relative Intensity
4338
4339
4340
4341
4342
4343
Wavelength (A)

Mgb2



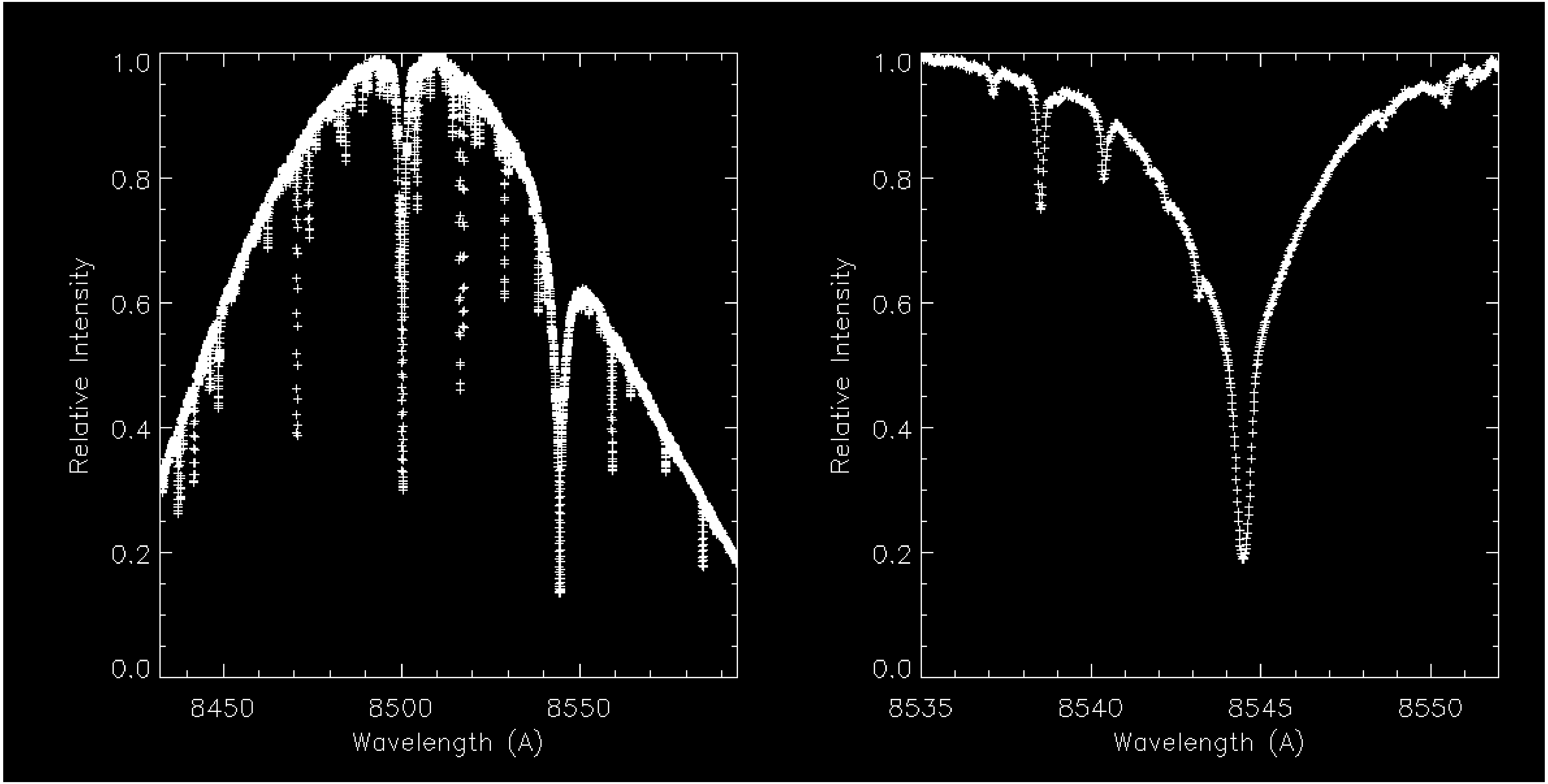
Relative Intensity
Wavelength (A)
0.0
0.2
0.4
0.6
0.8
1.0
5160
5180
5200
5220
5240
Relative Intensity
Wavelength (A)
0.0
0.2
0.4
0.6
0.8
1.0
5182
5183
5184
5185
5186
5187
5188

NaD1



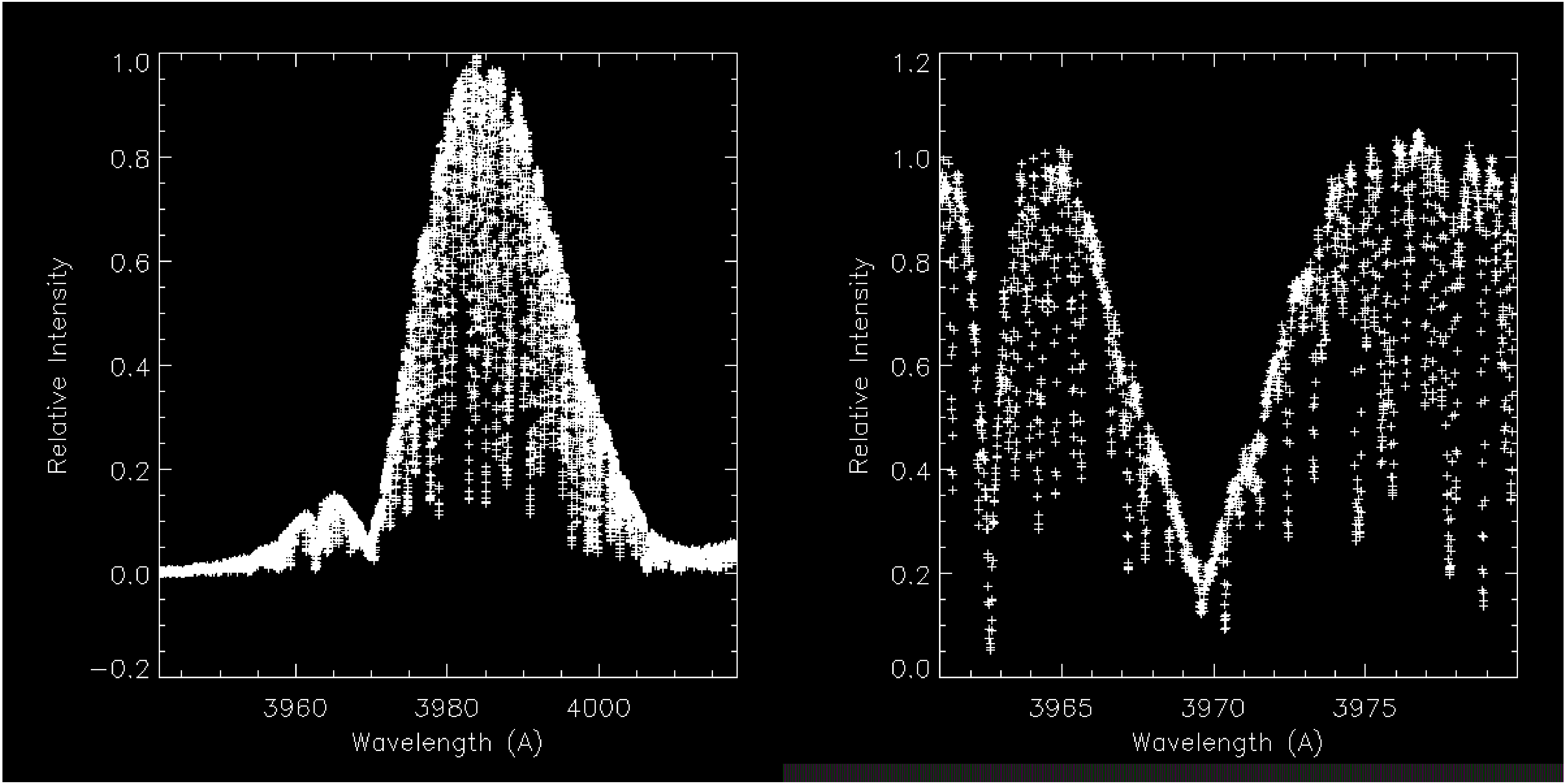
Relative Intensity
1.0
0.8
0.6
0.4
0.2
0.0
5840
5860
5880
5900
5920
5940
Wavelength (A)
Relative Intensity
1.0
0.8
0.6
0.4
0.2
0.0
5896.0
5896.5
5897.0
5897.5
5898.0
5898.5
Wavelength (A)

Ca I 8542



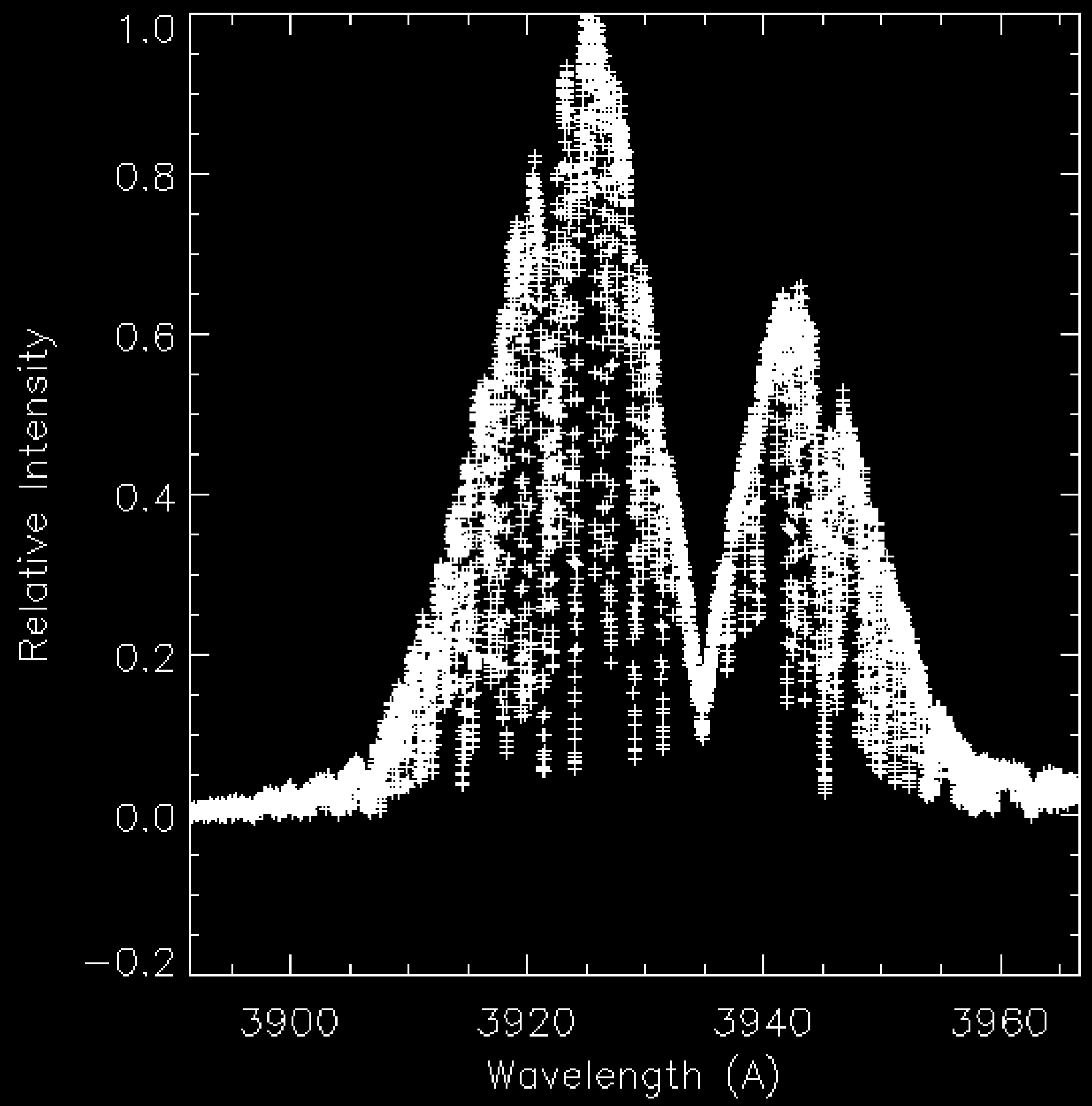
Relative Intensity
1.0
0.8
0.6
0.4
0.2
0.0
8450
8500
8550
Wavelength (A)
Relative Intensity
1.0
0.8
0.6
0.4
0.2
0.0
8535
8540
8545
8550
Wavelength (A)

Ca II H

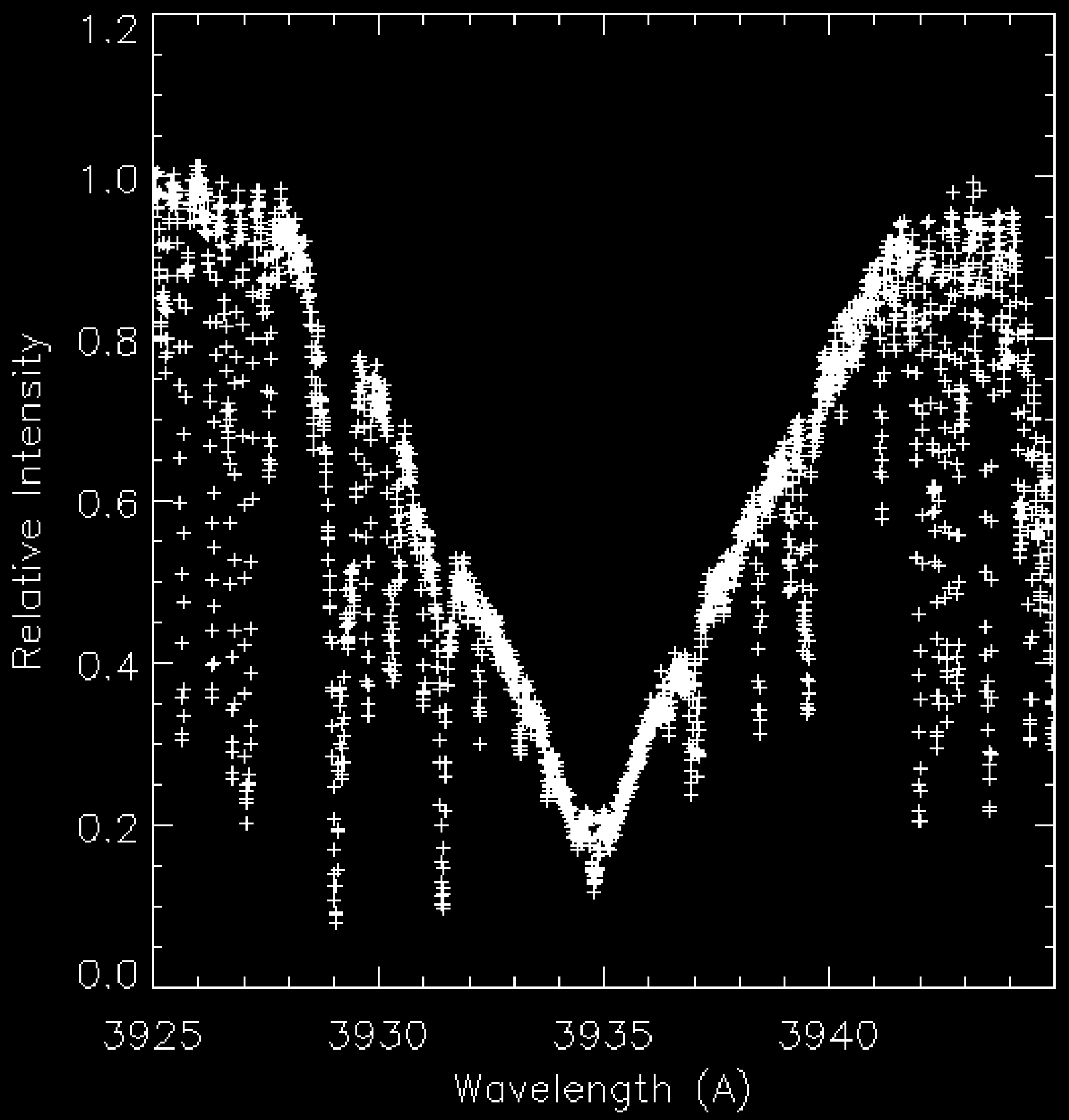


1.0
0.8
0.6
0.4
0.2
0.0
−0.2
Relative Intensity
3960
3980
4000
Wavelength (A)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Relative Intensity
3965
3970
3975
Wavelength (A)

Ca II K

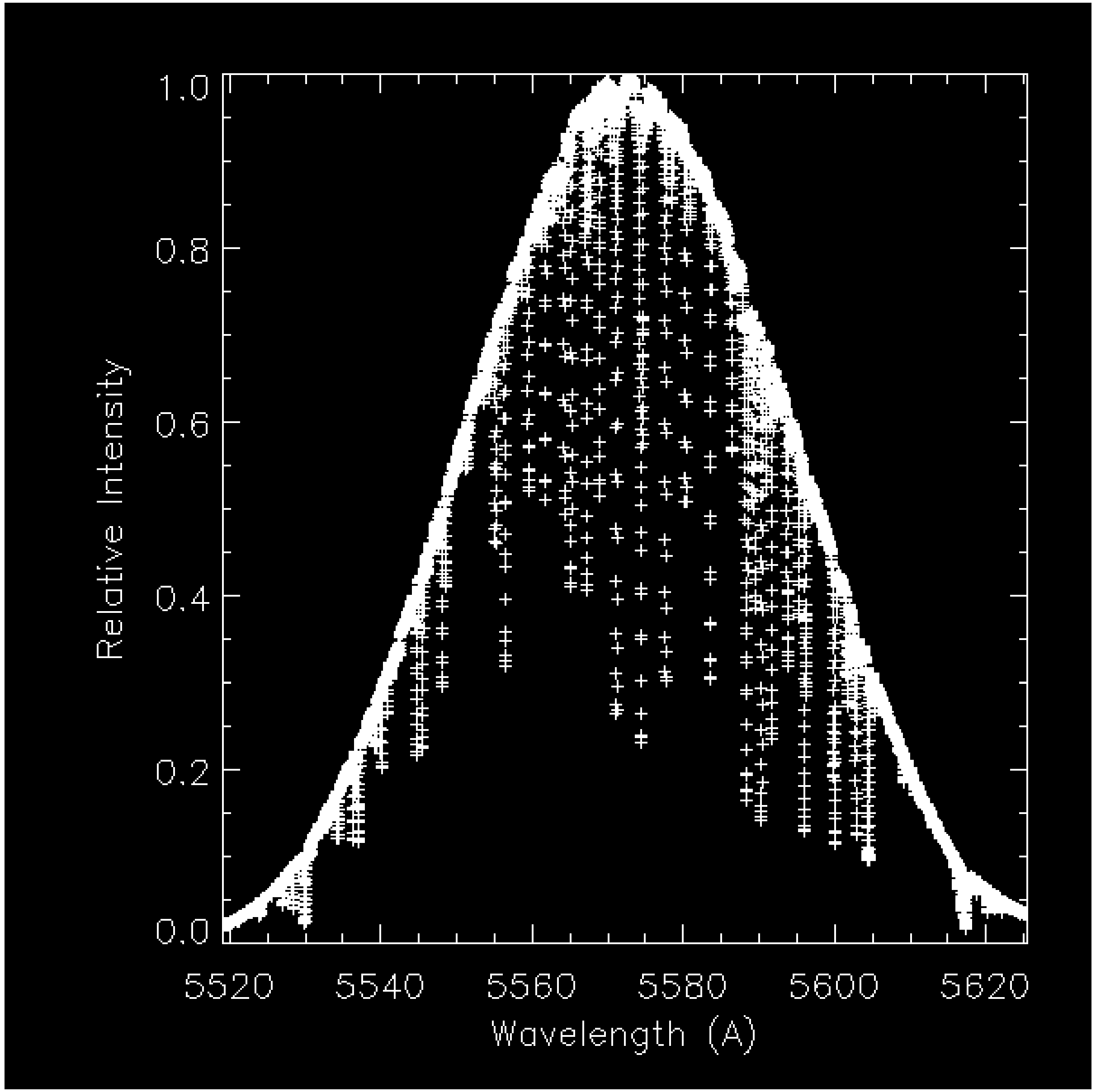


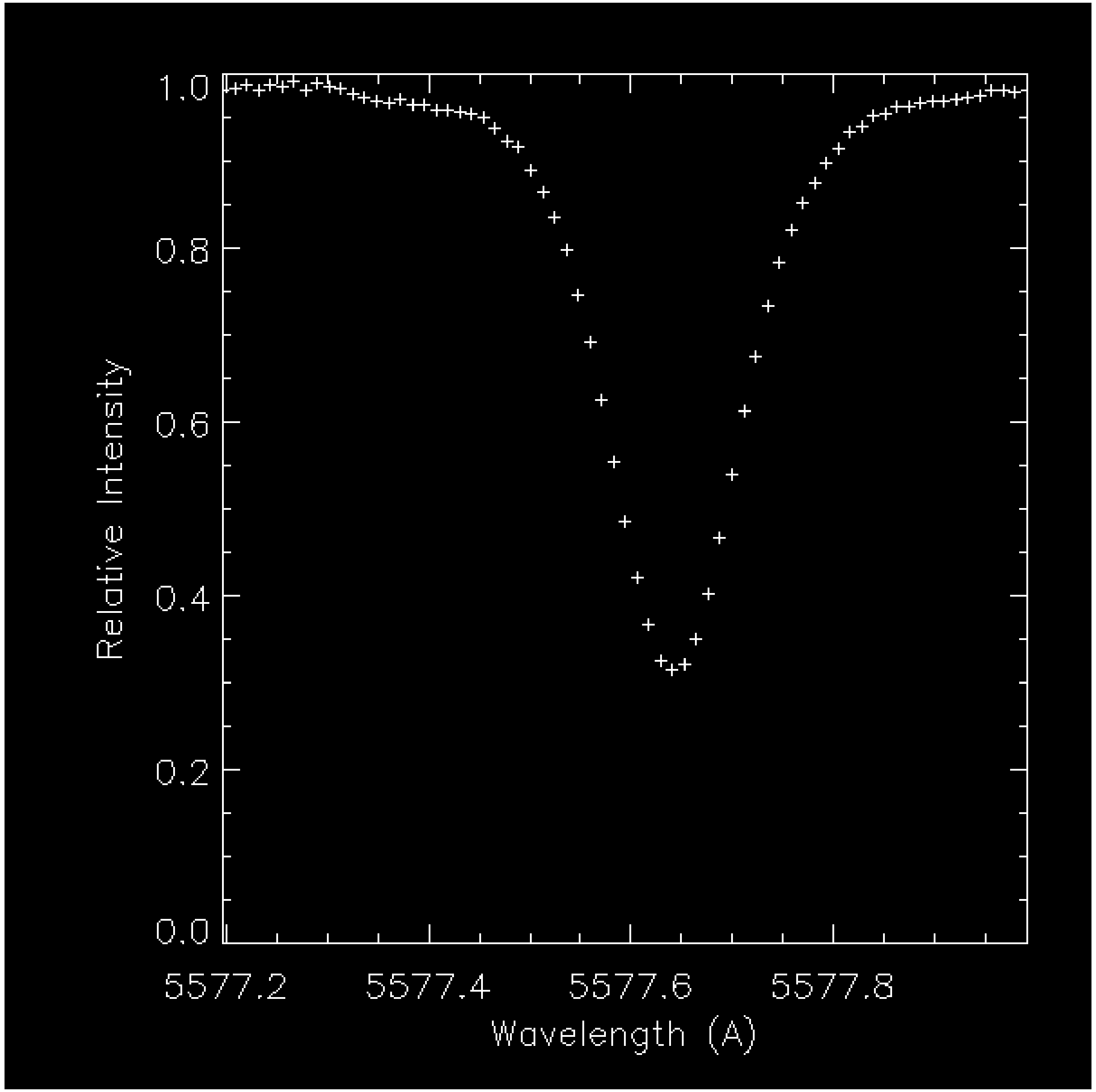
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
Relative Intensity
3900
3920
3940
3960
Wavelength (A)



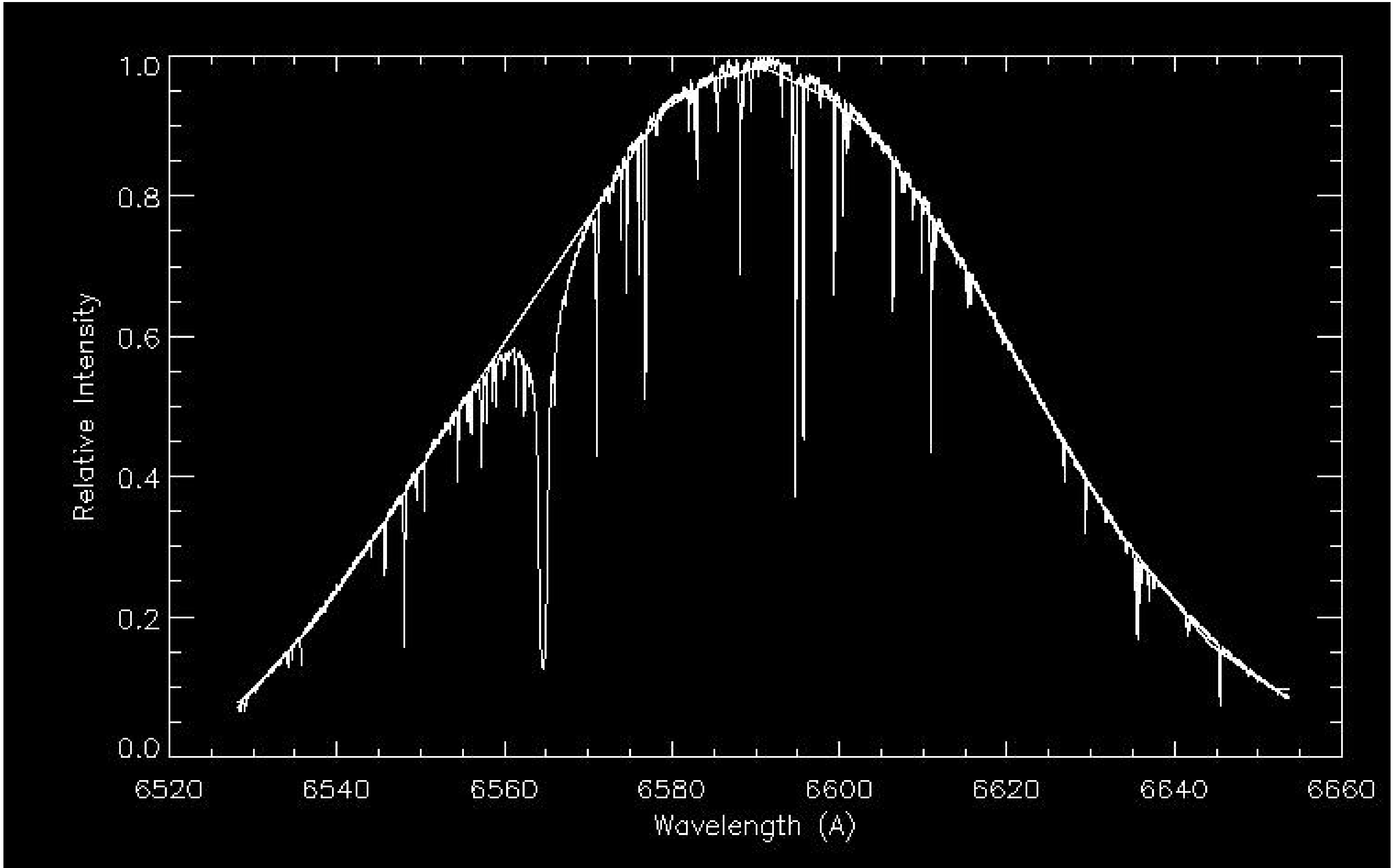
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Relative Intensity
3925
3930
3935
3940
Wavelength (A)

Fe I 5576 A Photospheric

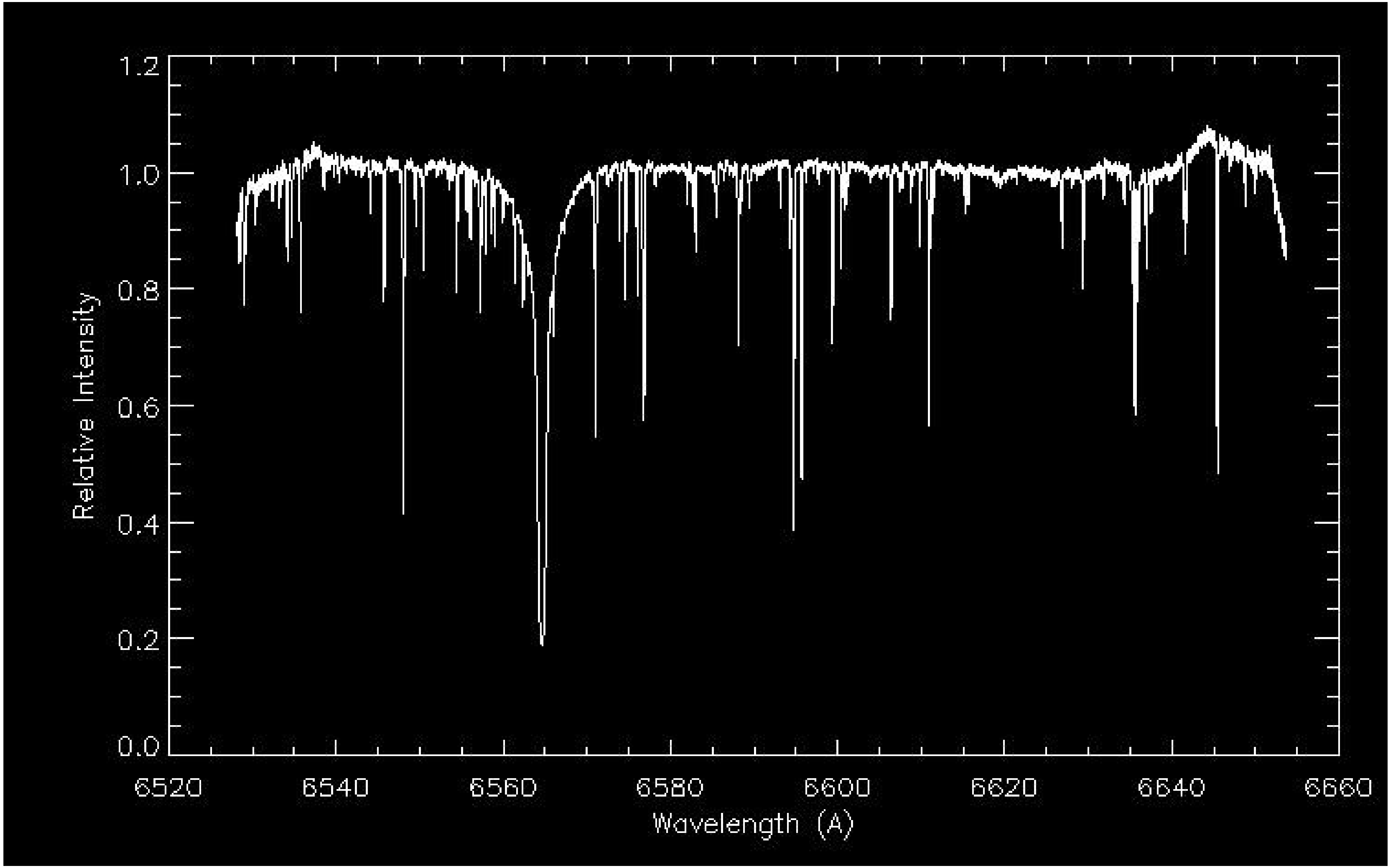




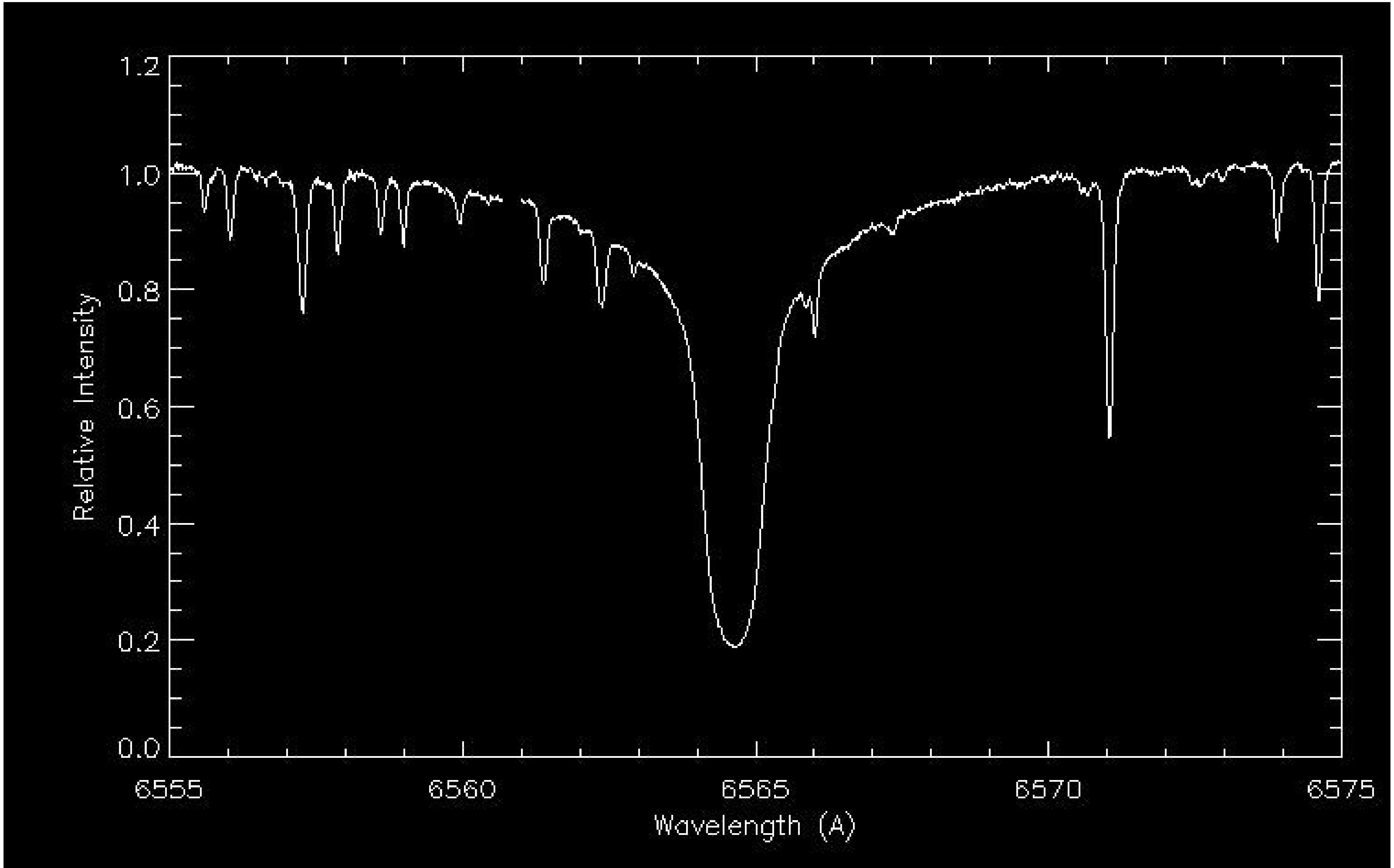
Order 80 with Halpha



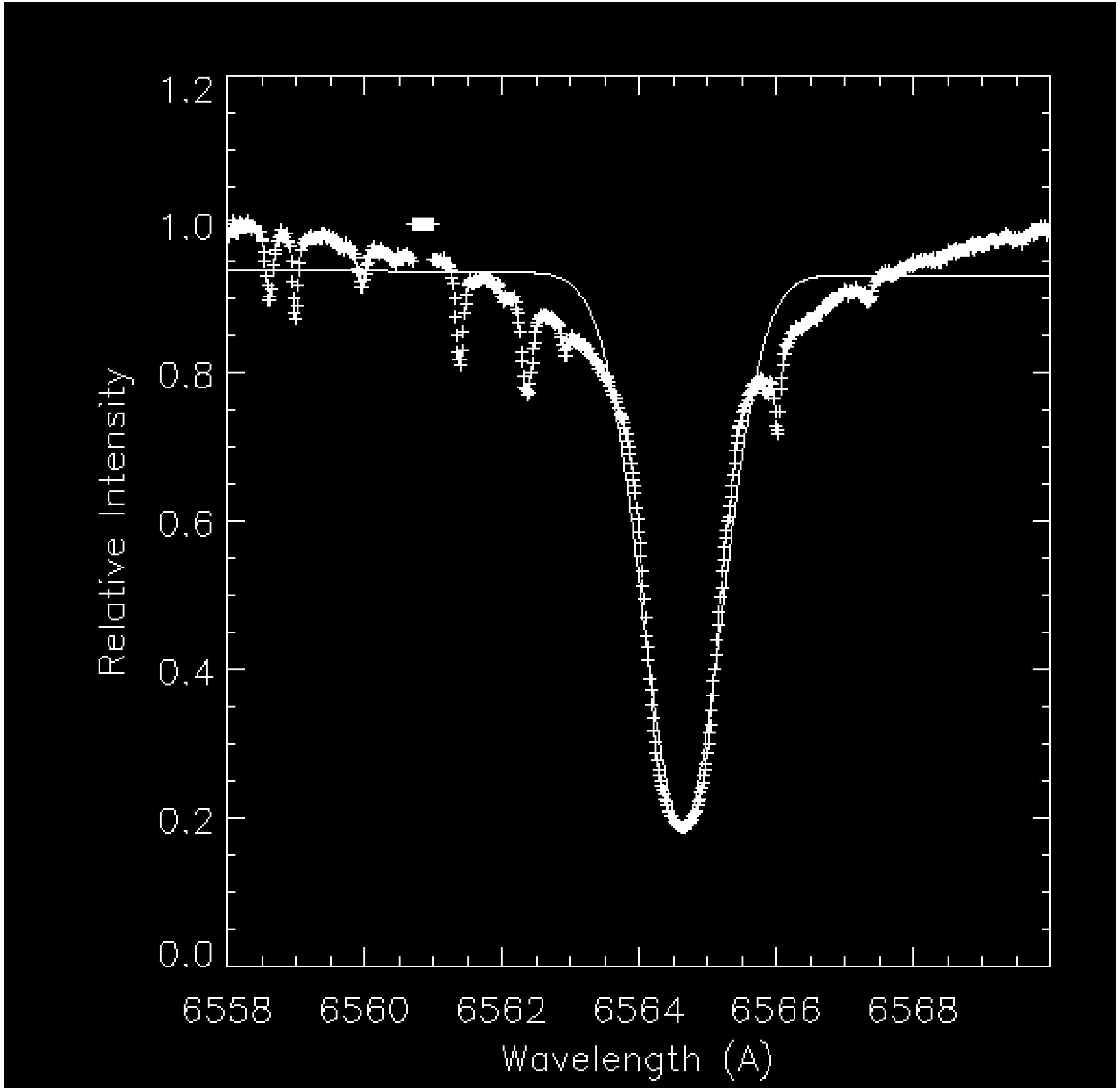
Background subtracted order 80



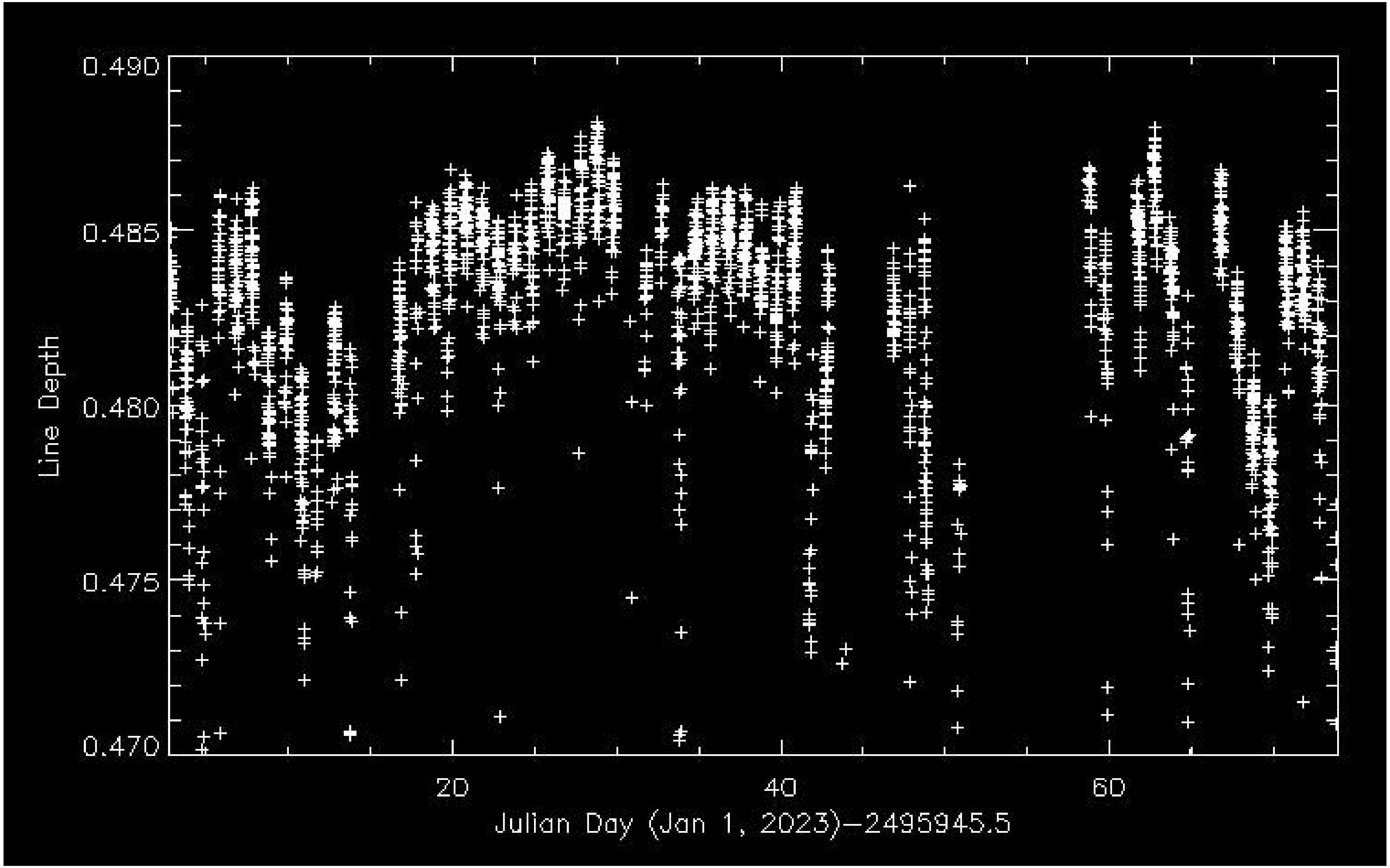
Halpha Spectra



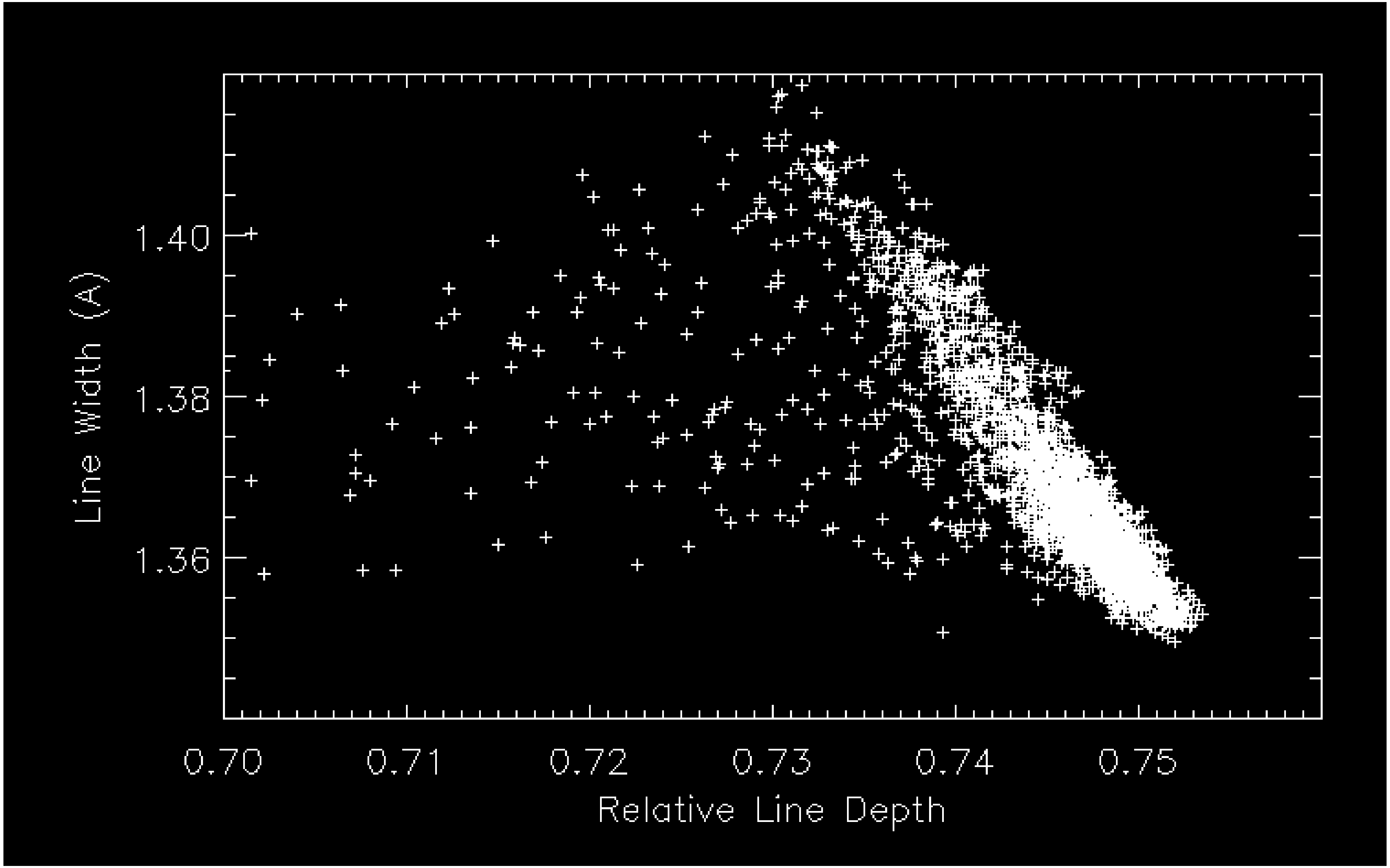
Halpha (Gaussfit)



Line Depth Time Series



Line Depth Vs Line Width



Summary

- We detect daily change of Halpha line depth possibly due to the temporal changes of active region distribution on the sun.

- Plan for Parameters to be measured

Indices of spectral lines

Line Depths

Full width at half maximum

Equivalent Widths

- Include the data from other instruments.

Thank you