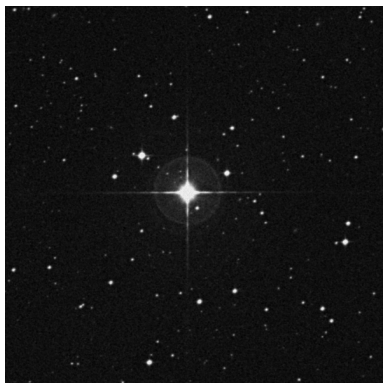
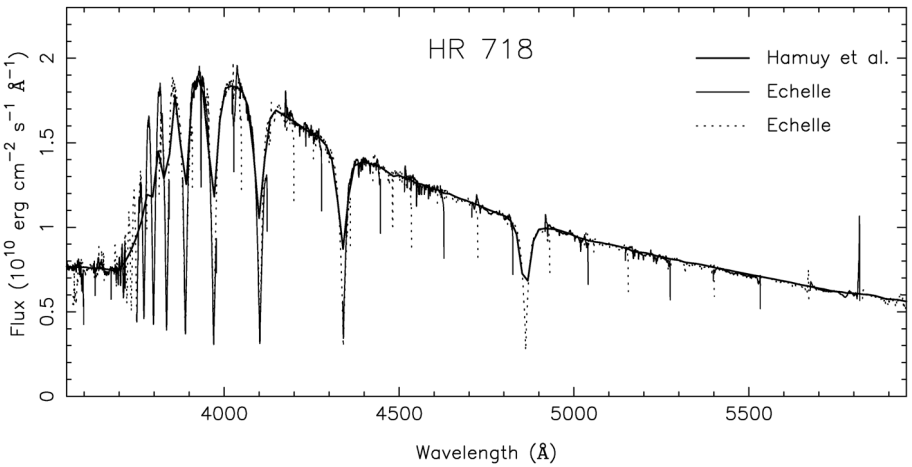
Absolute Flux Calibration of Sky Spectra Using Spectrophotometric Standard Stars

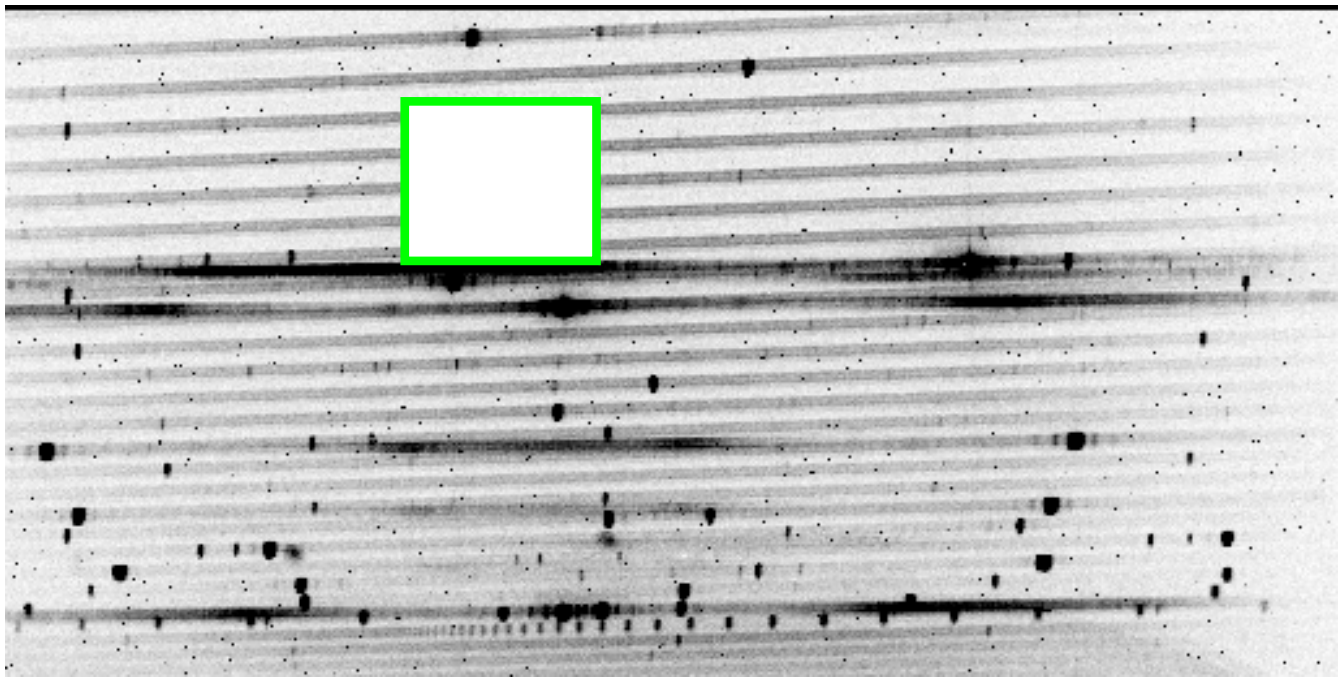


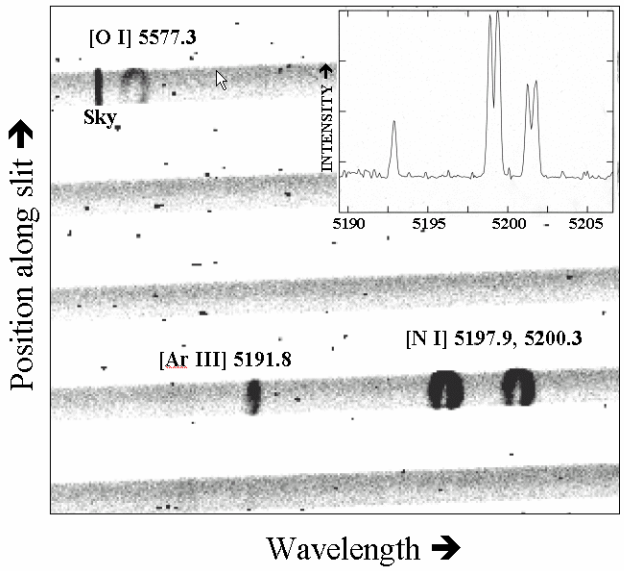


Brian Sharpee
Molecular Physics Laboratory
SRI International

CEDAR Workshop: Optical Calibration Techniques and Issues
June 30, 2004, Santa Fe, NM

1. Echelle Spectrographs





CTIO 4 meter echelle 2-D spectrum of planetary nebulae IC 418 (350-590 nm)

- Simultaneous imaging of 350 to 800 nm in single exposure
- Resolution ($\lambda/\delta\lambda$) = 5000 – 60000 (0.01 – 0.1 nm at 500 nm)

2. Spectrophotometric Standards:

- Featureless, metal poor ([Fe/H] < solar), dwarf, giant, white dwarf stars (Oke 1990, Astron. J.; Hamuy et al. 1994, Pub. Astron. Soc. Pac.) tabulated absolute flux referenced to Vega.

- Goal: Establish transfer function: multiplicative factor to multiply object spectra to flux calibrate

Advantages:

- Simultaneous, full range (400-800 nm for most standards), absolute flux calibration
- Little time investment to observe
- Stars numerous and widespread

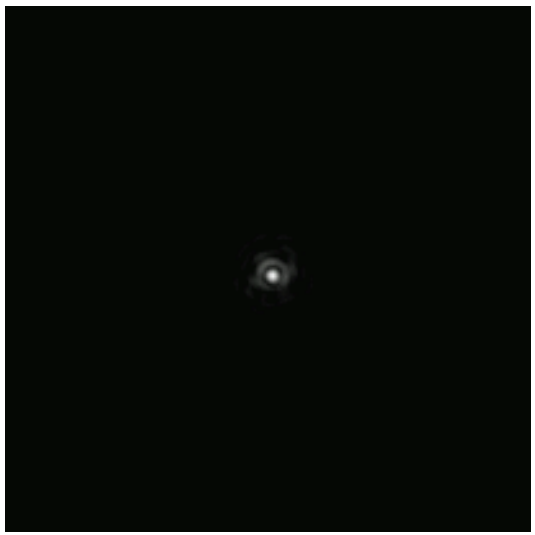
Disadvantages:

- Labor intensive to reduce
- Accuracy may vary with type of spectrographs
  > Light losses versus telescope position (coude, HIRES)

3. Observation/Reduction Procedures:

- Reductions carried out by Instrument Reduction and Analysis Facility (IRAF), comparable routines available for other astronomical reduction packages/some archival pipeline routines.

3. Observation/Reduction Procedures:



Typical standard star with simulated (bad) seeing

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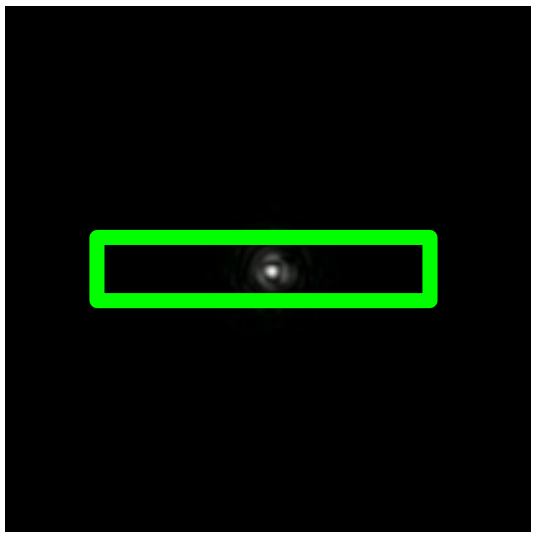

Typical standard star with simulated (bad) seeing

1. Observe numerous stars (2 to 3 times (each night, 3 or more stars), bracket time/spatial location of objects

Use large slit (cover whole seeing disk), orient to parallactic angle

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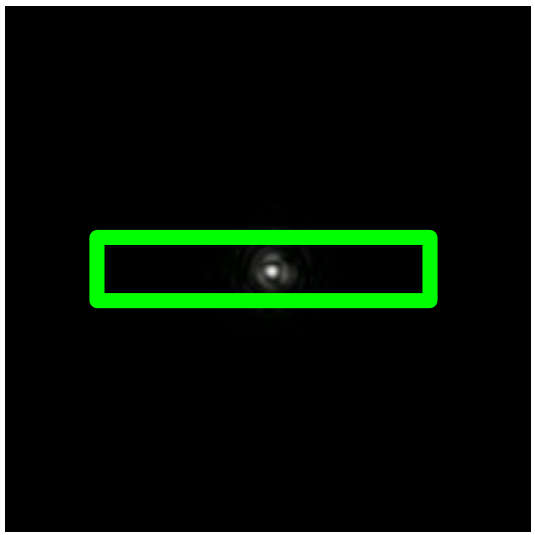

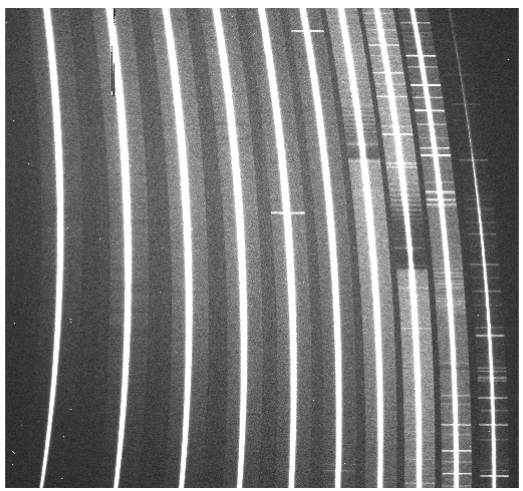

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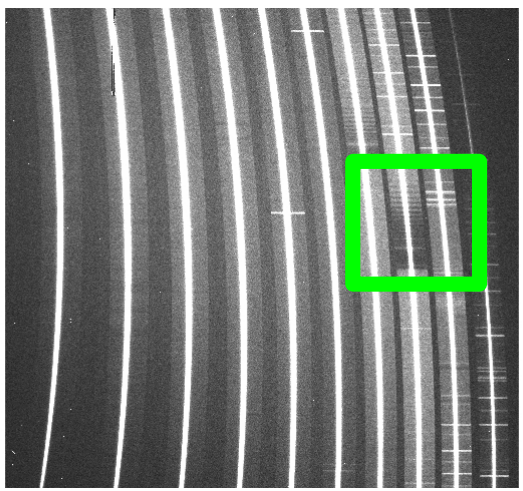
ESI (Keck II) 2-D spectrum



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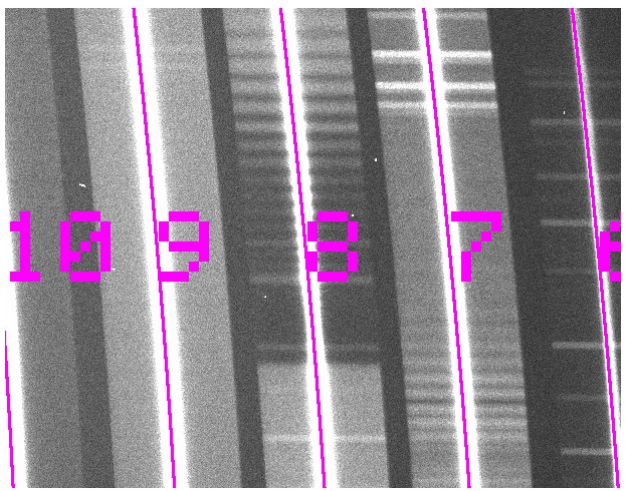

Trace

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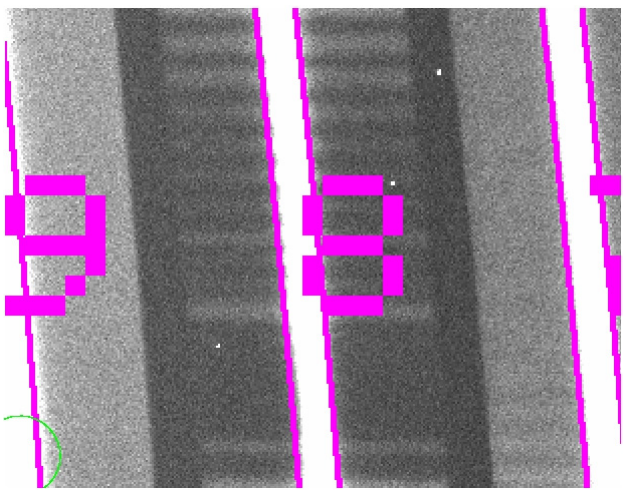

Extract / sum along slit

Background subtract

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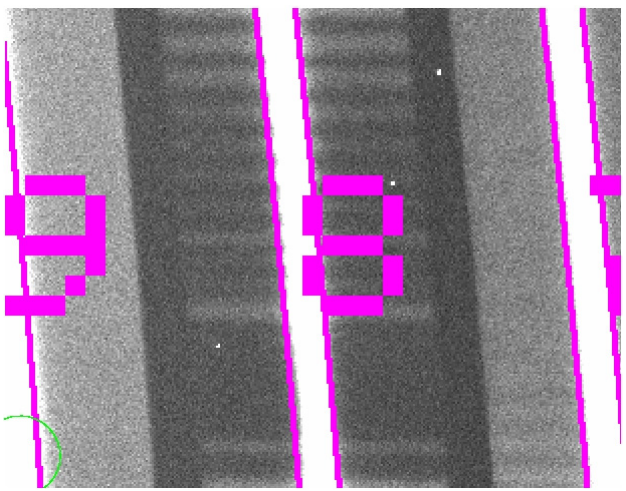

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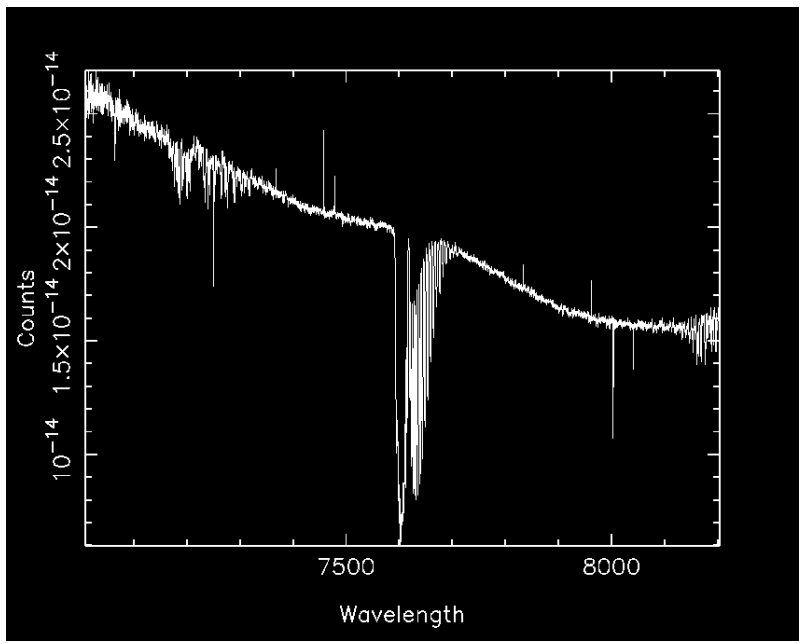
Wavelength calibrate (ThAr lamp)



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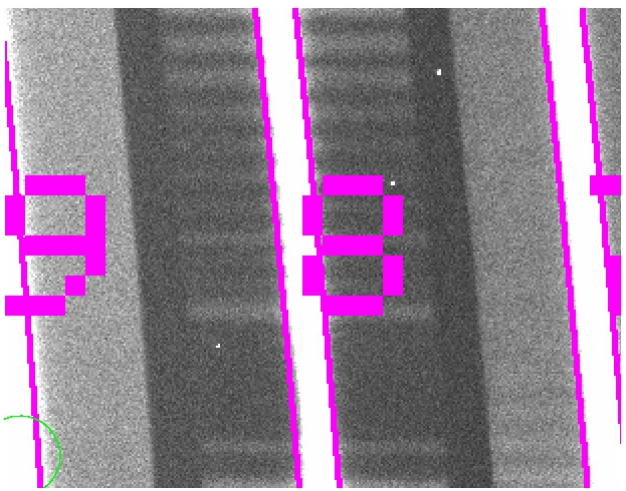

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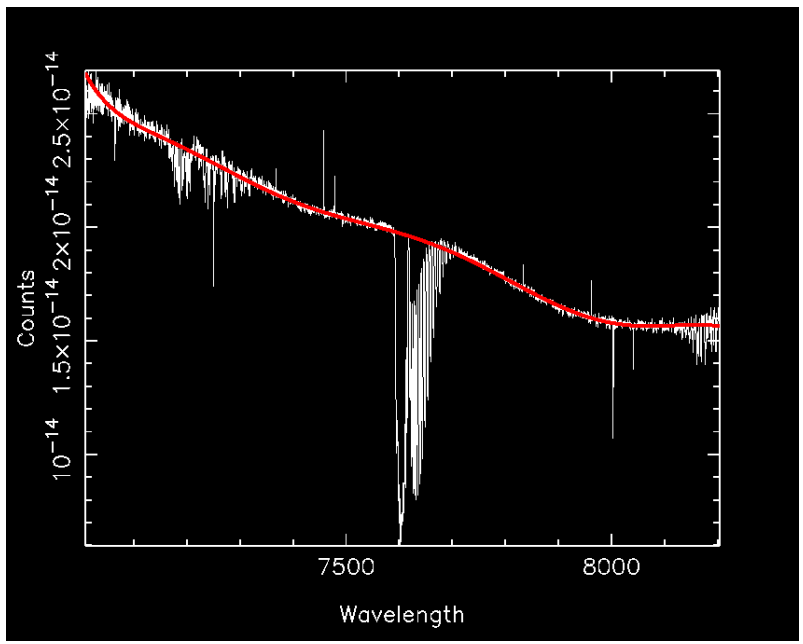
Wavelength calibrate (ThAr lamp)

Divide out blackbody, telluric standard, or fit continuum



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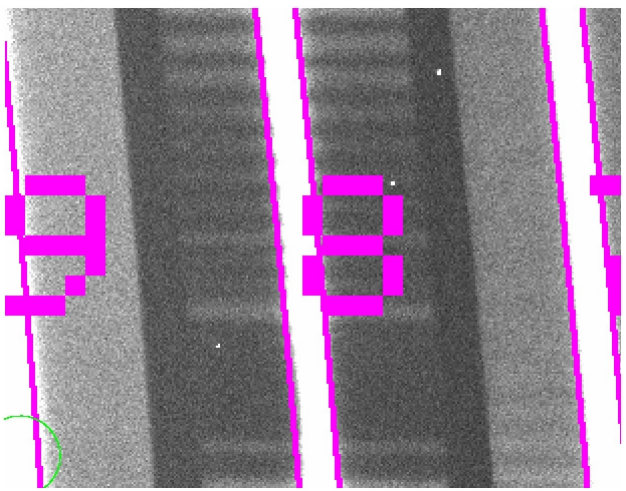

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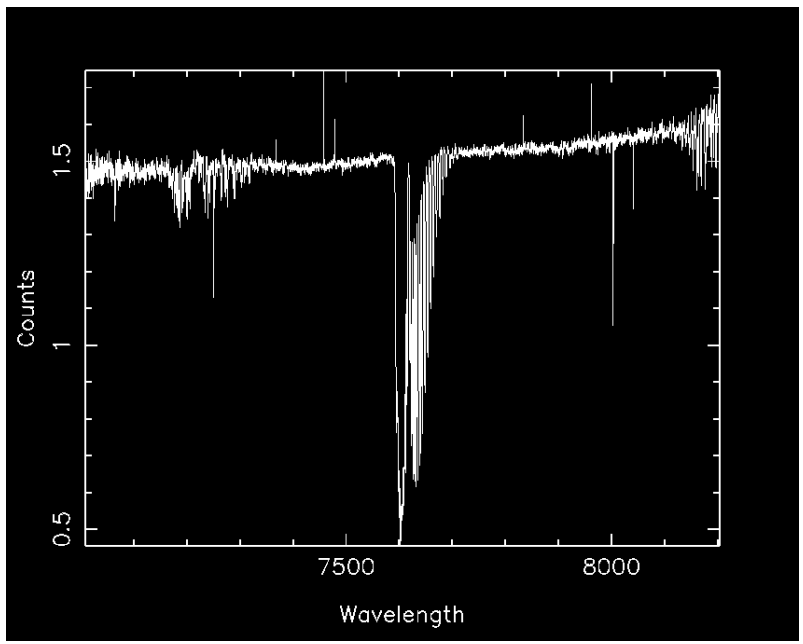

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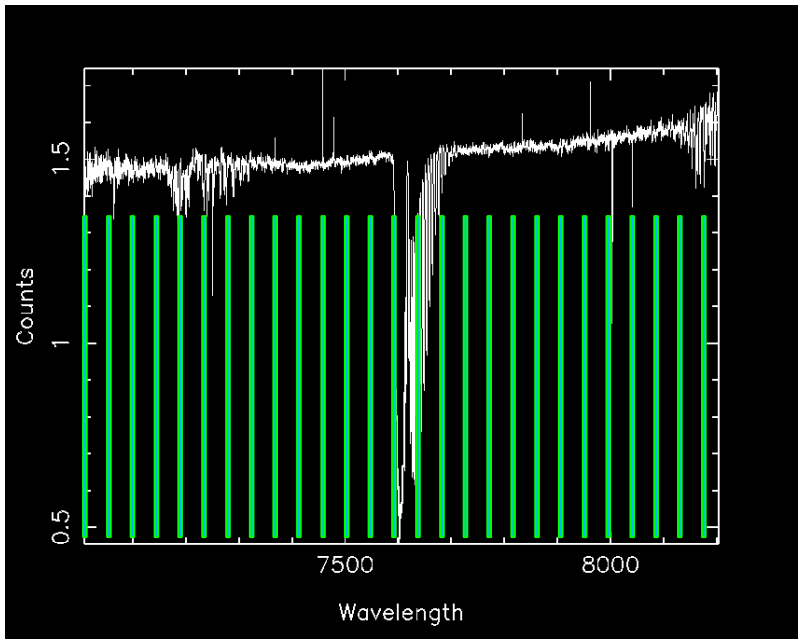
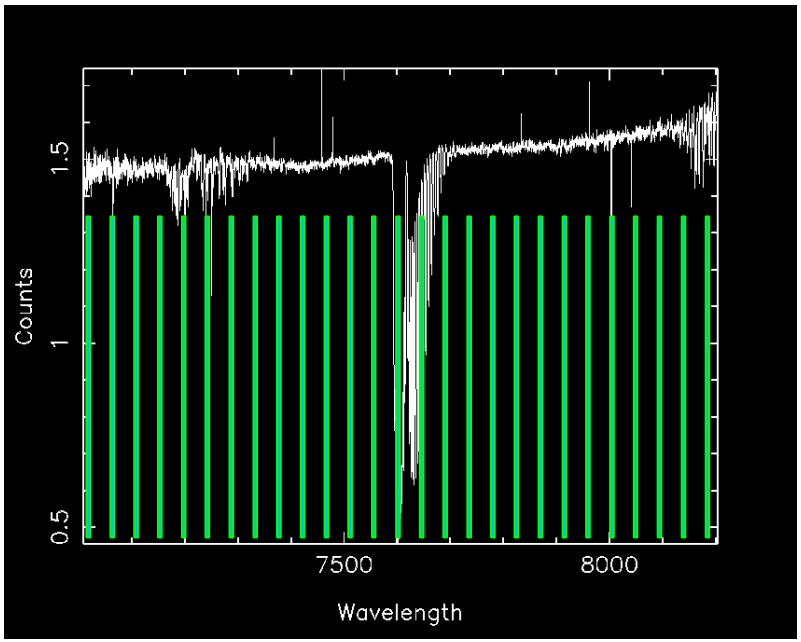


Standard Star Feige 110 binned at 5 nm intervals (Oke 1990, Astron. J.)

1. Observe numerous stars (2 to 3 times (each night, 3 or more stars), bracket time/spatial location of objects
2. Convert 2-D spectrum to wavelength calibrated 1-D spectrum
3. Bin spectrum at tabulated wavelengths

3. Observation/Reduction Procedures:



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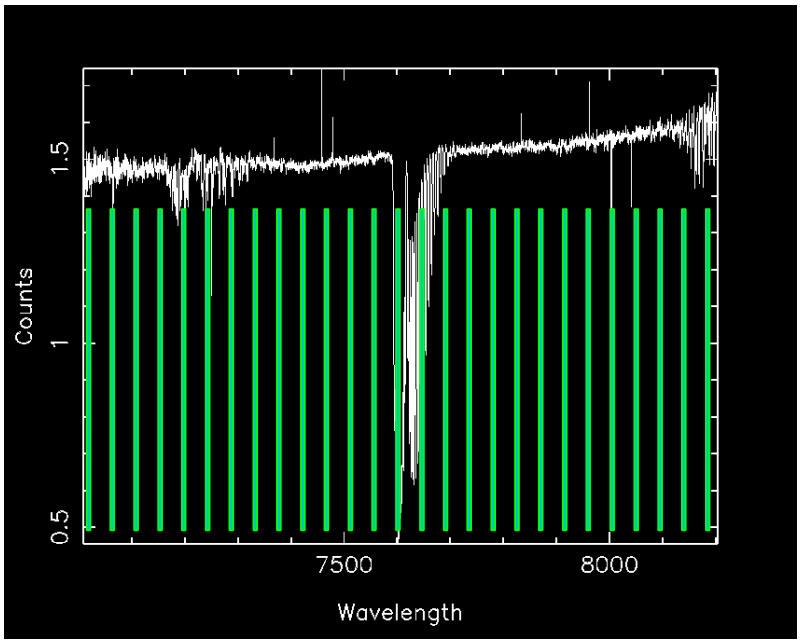
Compute counts in observed spectrum

$$O = \sum_{i=1}^{\Delta\lambda/disp} c_i \,,$$

$\Delta\lambda \equiv$ bandpass width (nm)
$disp \equiv$ nm/pixel (usually linearly binned)
$c_i \equiv$ counts per pixel i within bandpass

3. Observation/Reduction Procedures:



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Compute star tabulated flux at same points

$$F = \frac{c}{\lambda_o^2} F_o \times 10^{-M_{AB}/2.5},$$

$c \equiv 3.0 \times 10^{17}$ nm s^{-1}
$\lambda_o \equiv$ bandpass center wavelength (nm)
$F_o \equiv 3.68 \times 10^{-20}$ erg cm^{-2} s^{-1} Hz^{-1}
$M_{AB} \equiv$ magnitude of standard star

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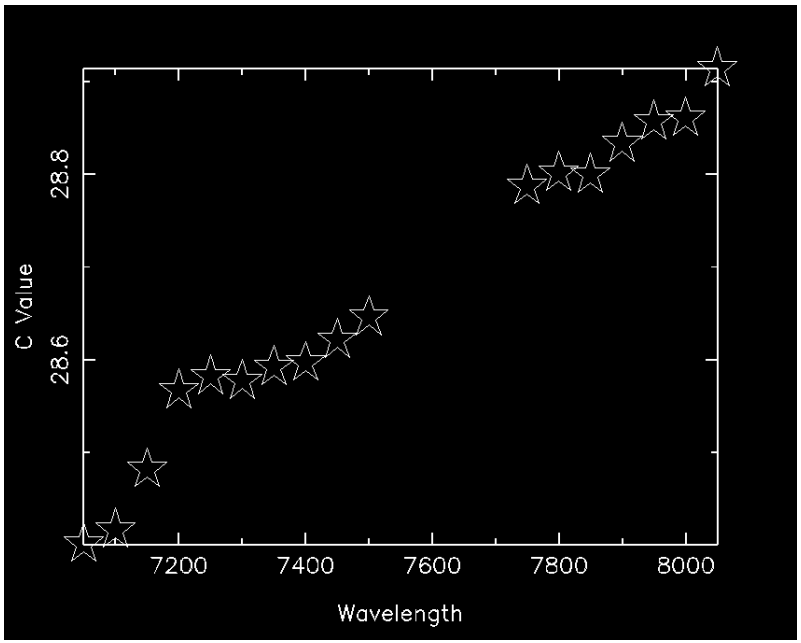


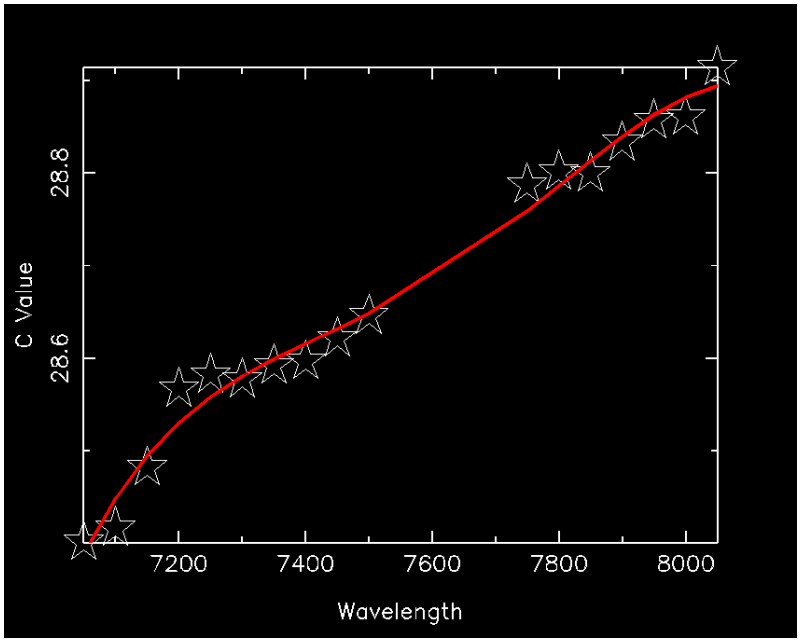
Calculate Calibration Points

1. Observe numerous stars (2 to 3 times (each night, 3 or more stars), bracket time/spatial location of objects
2. Convert 2-D spectrum to wavelength calibrated 1-D spectrum
3. Bin spectrum at tabulated wavelengths
4. Determine sensitivity function

$$C = 2.5 \log_{10} \frac{O}{TF\Delta\lambda} + AE,$$

$C \equiv$ "calibration" factor
$T \equiv$ exposure time (s)
$A \equiv$ number of airmasses
$E \equiv$ extinction table magnitudes of flux per airmass

3. Observation/Reduction Procedures:



Fit Calibration Points

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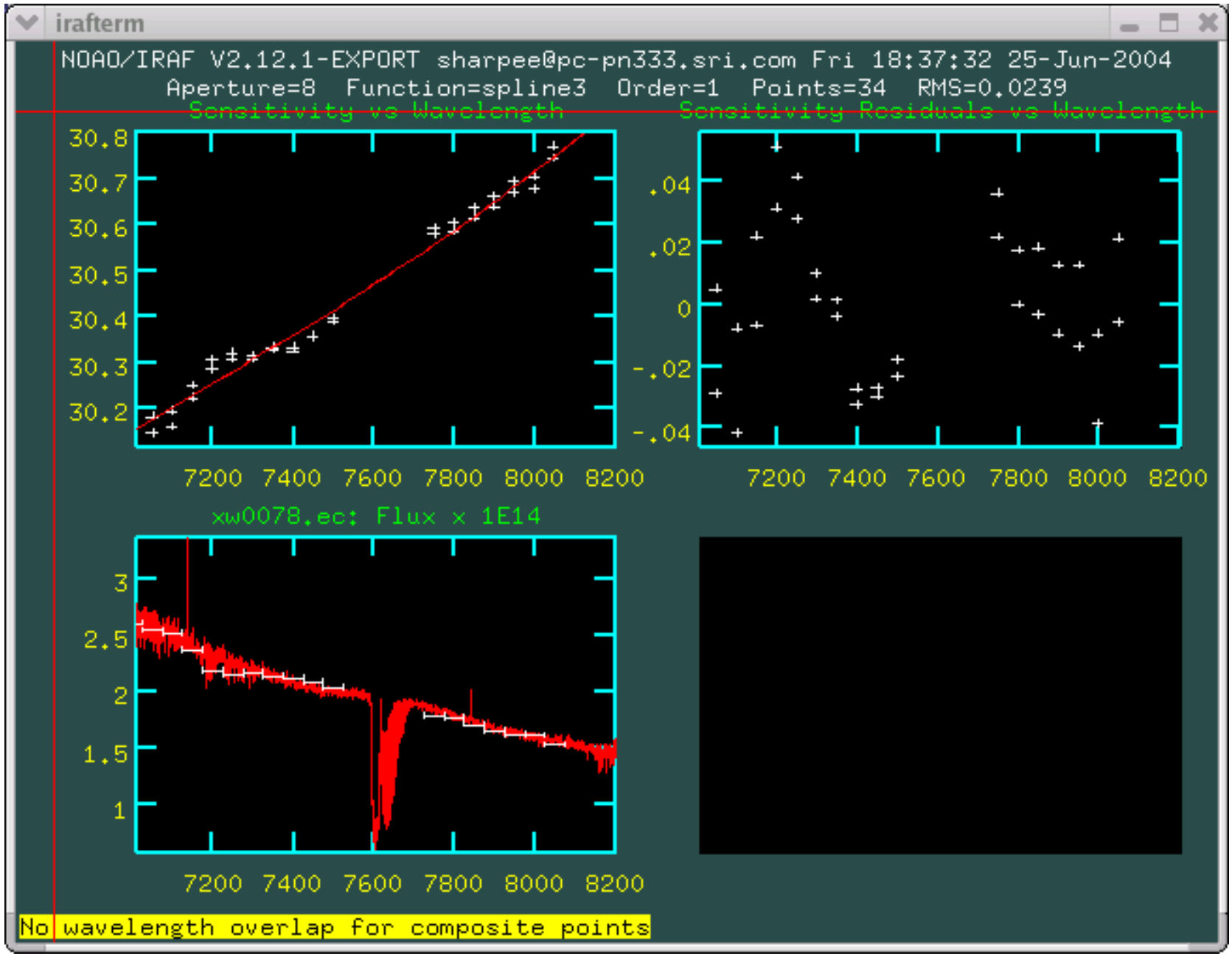
4. Determine sensitivity function

$$C = S(\lambda) + AE(\lambda),$$

where $S(\lambda)$ and $E(\lambda)$ are functions of wavelength λ in each order

low order polynomial/spline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NOAO/IRAF V2.12.1-EXPORT sharpee@pc-pn333.sri.com Fri 18:37:32 25-Jun-2004
Aperture=8 Function=spline3 Order=1 Points=34 RMS=0.0239
Sensitivity vs Wavelength
Sensitivity Residuals vs Wavelength
30.8
30.7
30.6
30.5
30.4
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7200 7400 7600 7800 8000 8200
7200 7400 7600 7800 8000 8200
xw0078.ec: Flux x 1E14
3
2.5
2
1.5
1
7200 7400 7600 7800 8000 8200
No wavelength overlap for composite points

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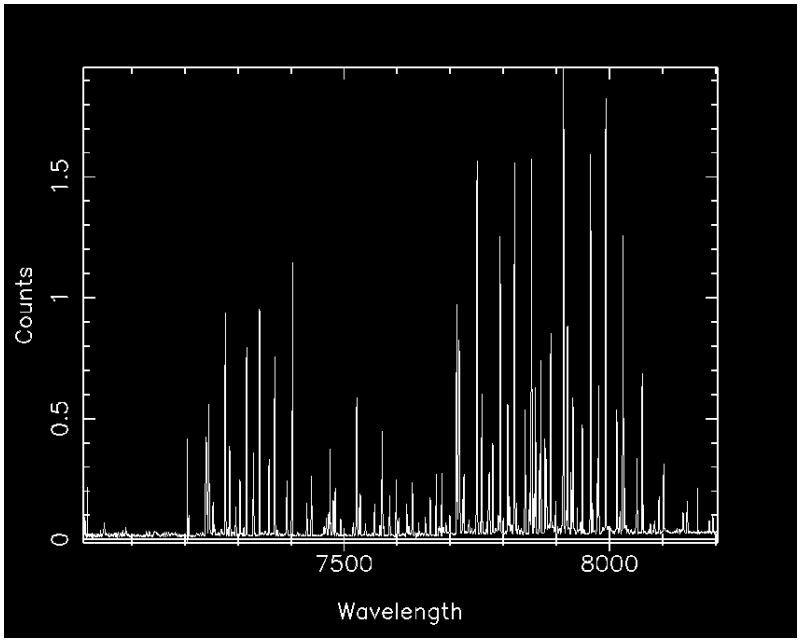

Before flux calibration

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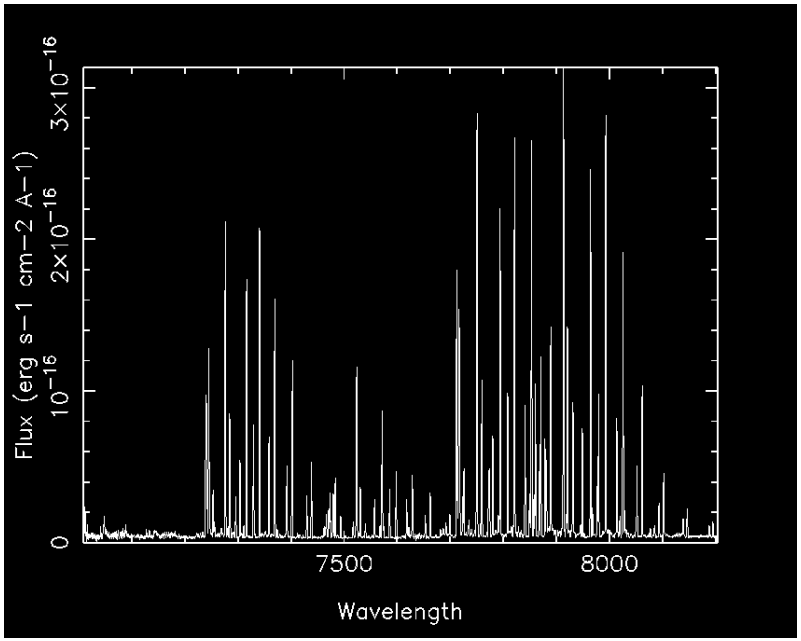
4. Determine sensitivity function
5. Apply sensitivity function and extinction to star and object spectra

$$F(\lambda) = \frac{C(\lambda)}{S(\lambda)T \times disp(\lambda)},$$

$C(\lambda) \equiv$ counts
$S(\lambda) \equiv$ sensitivity function
$T \equiv$ exposure time (s)
$disp(\lambda) \equiv$ nm/pix (linear dispersion)

3. Observation/Reduction Procedures:



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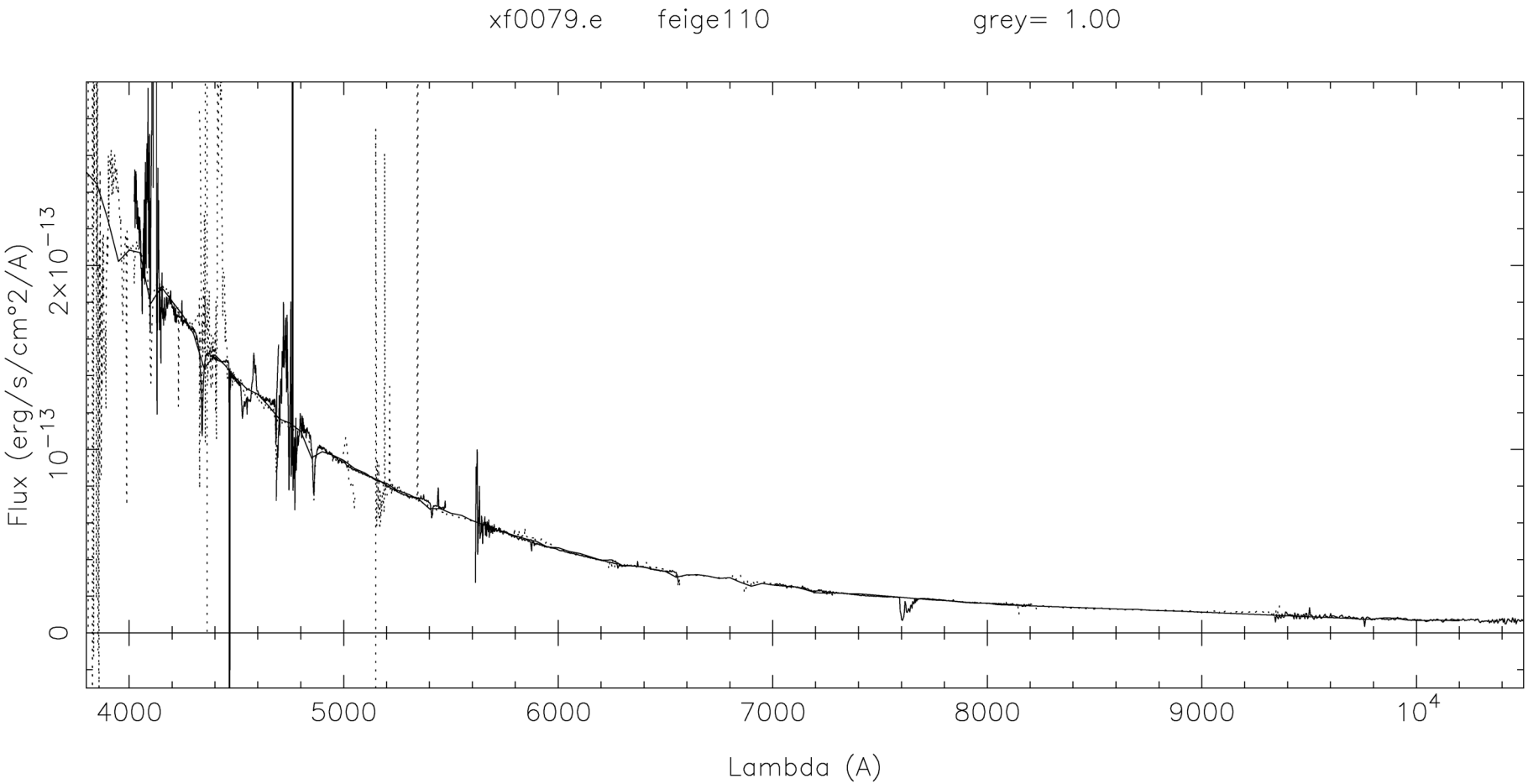
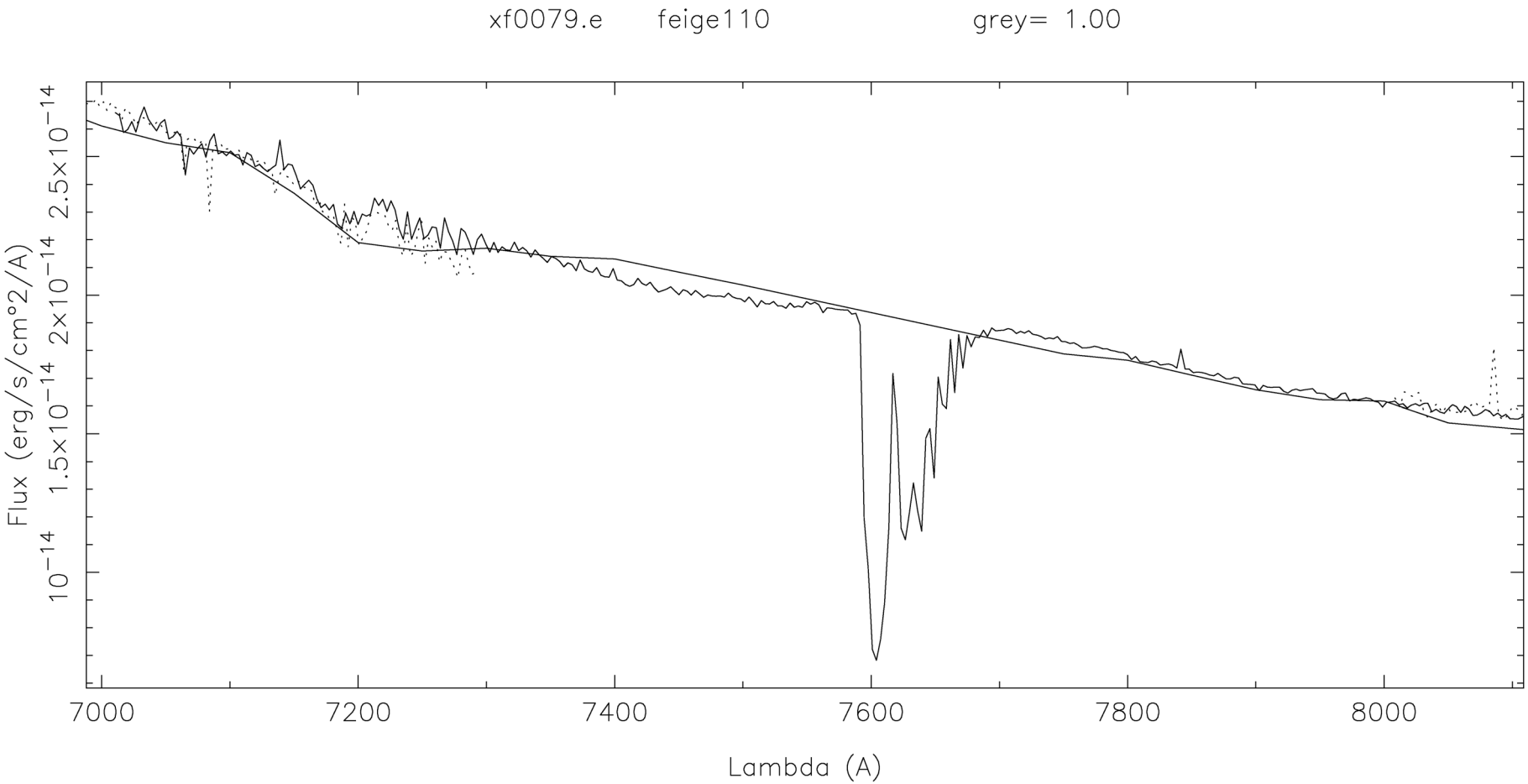
4. Results


xf0079.e
feige110
grey= 1.00
Flux (erg/s/cm^2/A)
2×10^-13
10^-13
0
4000
5000
6000
7000
8000
9000
10^4
Lambda (A)

4. Results


xf0079.e
feige110
grey= 1.00
Flux (erg/s/cm^2/A)
10^-14
1.5x10^-14
2x10^-14
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8000
Lambda (A)

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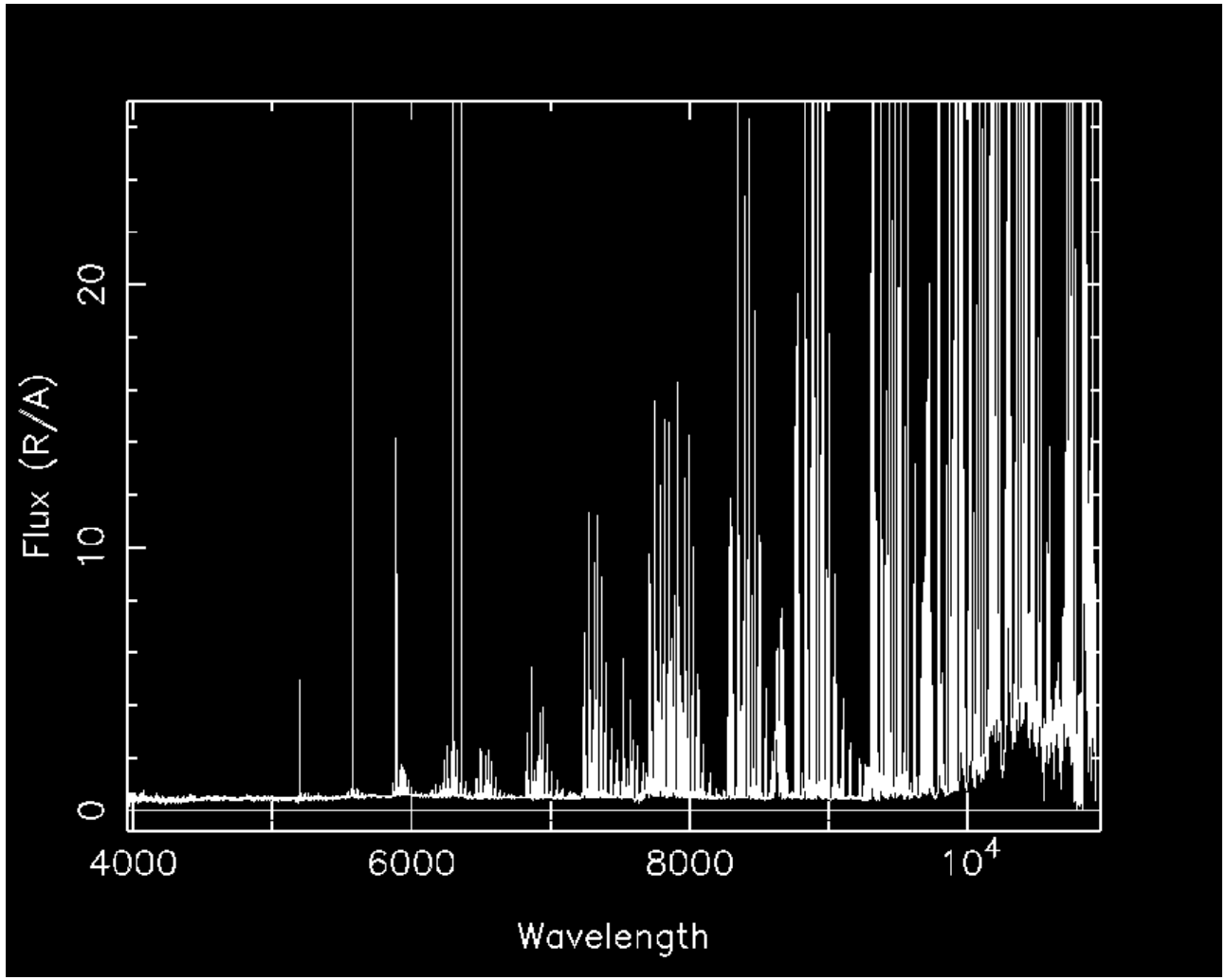

5. Conclusions

- Spectrophotmetric standard stars allow an absolute flux calibration to be obtained across the observable range of your spectra with a reasonable degree of accuracy

- Techniques for the automation of the reduction process under development