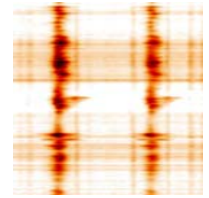




SKYLAB - HRTS



# Center-to-Limb Variation of the Solar UV Spectrum Observed by SKYLAB

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# Abstract

As part of an ongoing effort to develop a solar spectral UV irradiance model in the 200 - 400nm wavelength range using SKYLAB spectra, we are determining the quiet sun center-to-limb variation (CLV) at high resolution ( $\sim 0.010$  nm at 300 nm). Solar UV spectral radiance has been determined for the quiet sun at a variety of center-to-limb positions observed by the SO82B UV spectrograph on SKYLAB. The SKYLAB film data has been digitized using a high quality flatbed scanner. The irradiance model requires detailed knowledge of the center-to-limb variation (CLV) at full resolution over the 200 - 400nm wavelength range. In this presentation we will present the details of the analysis methods and results so far for the quiet sun. This effort is part of a NASA-LWS sponsored research program.

# Outline

- Importance of Center-to-Limb Variation
- Overview of Irradiance Model & Results
- Previous Results from HRTS-9
- Scanning Photographic SKYLAB Data
- Present Results from SKYLAB
- Future Work
- Conclusions

# Importance of Center-to-Limb Variation Of Solar Spectrum

- Necessary to model solar spectral irradiance from disk-center radiance
- Examines the radiative properties of the solar atmosphere
- Because of height dependence of different emitting/absorbing species different surface features (quiet, active, sunspot) will have changes in CLV with wavelength

# Overview of Solar Spectral Irradiance Model & Results

## □ Mathematical formulation

$$F_{\text{FD}}(\lambda) = \sum_{i(\text{QS})} B_{\text{QS}}(\lambda) \text{CLV}(\lambda, i) \Delta A + \sum_{j(\text{AR})} B_{\text{AR}}(\lambda) \text{CLV}(\lambda, j) \Delta A \\ + \sum_{k(\text{SS})} B_{\text{SS}}(\lambda) \text{CLV}(\lambda, k) \Delta A$$

$F_{\text{FD}}(\lambda)$  = Full disk solar irradiance

$B_{\text{QS}}(\lambda)$  = Disk center Quiet Sun brightness.

$B_{\text{AR}}(\lambda)$  = Disk center Active Region brightness

$B_{\text{SS}}(\lambda)$  = Disk center Sun Spot brightness.

$\text{CLV}(\lambda, k)$  = Quiet Sun limb CLV.

$\Delta A$  = Angular size of the Ca II K pixels.

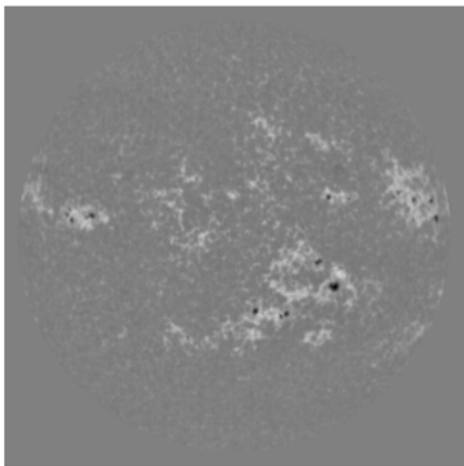
## □ Wavelength Coverage - 2760 to 2880 Å (HRTS-9) - ~1200 to 3940 Å (SKYLAB)

## □ Empirical Input - Quiet Sun, Active Region, and Sun Spot Spectra (calibrated) - Solar surface regions identified by full disk Ca II K images - High Resolution Wavelength dependent CLV

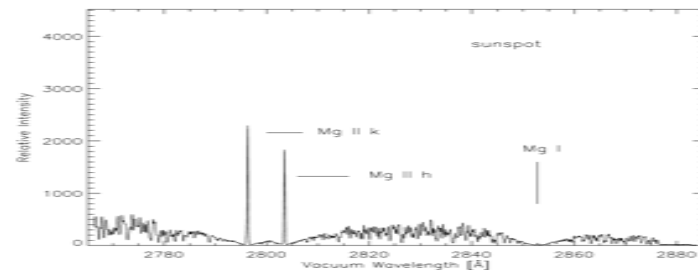
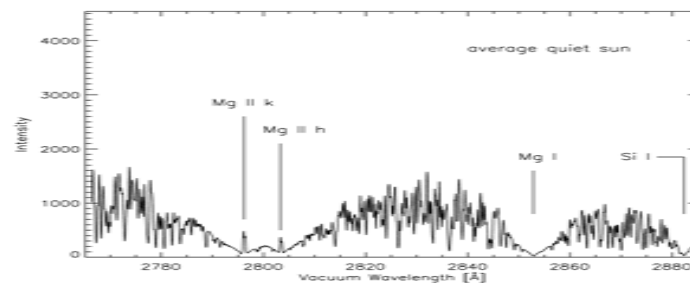
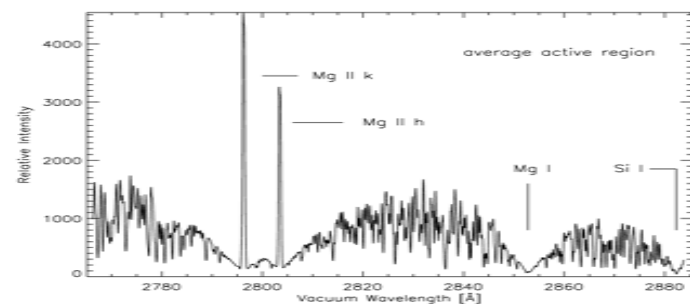
## □ Planned Comparison - Compare model with HiRes spectral data & Mg II indices.

# Overview of Irradiance Model & Results

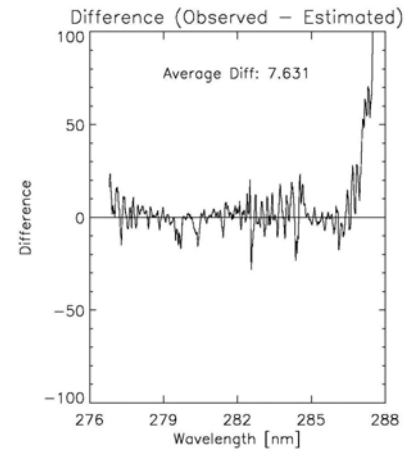
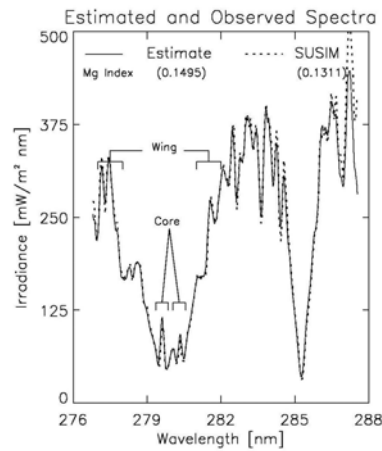
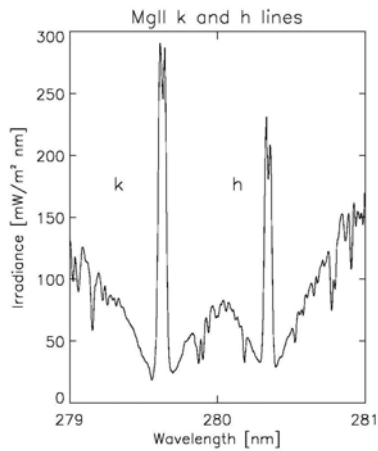
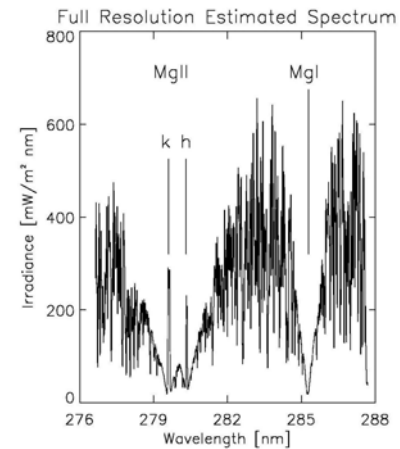
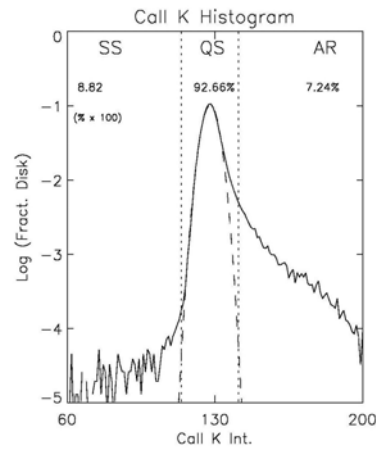
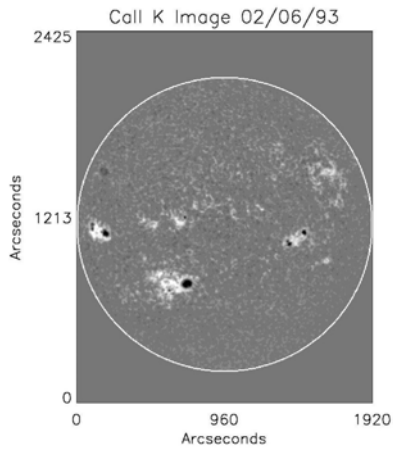
**BBSO Ca II K image (1/10/92)  
corrected for limb darkening**



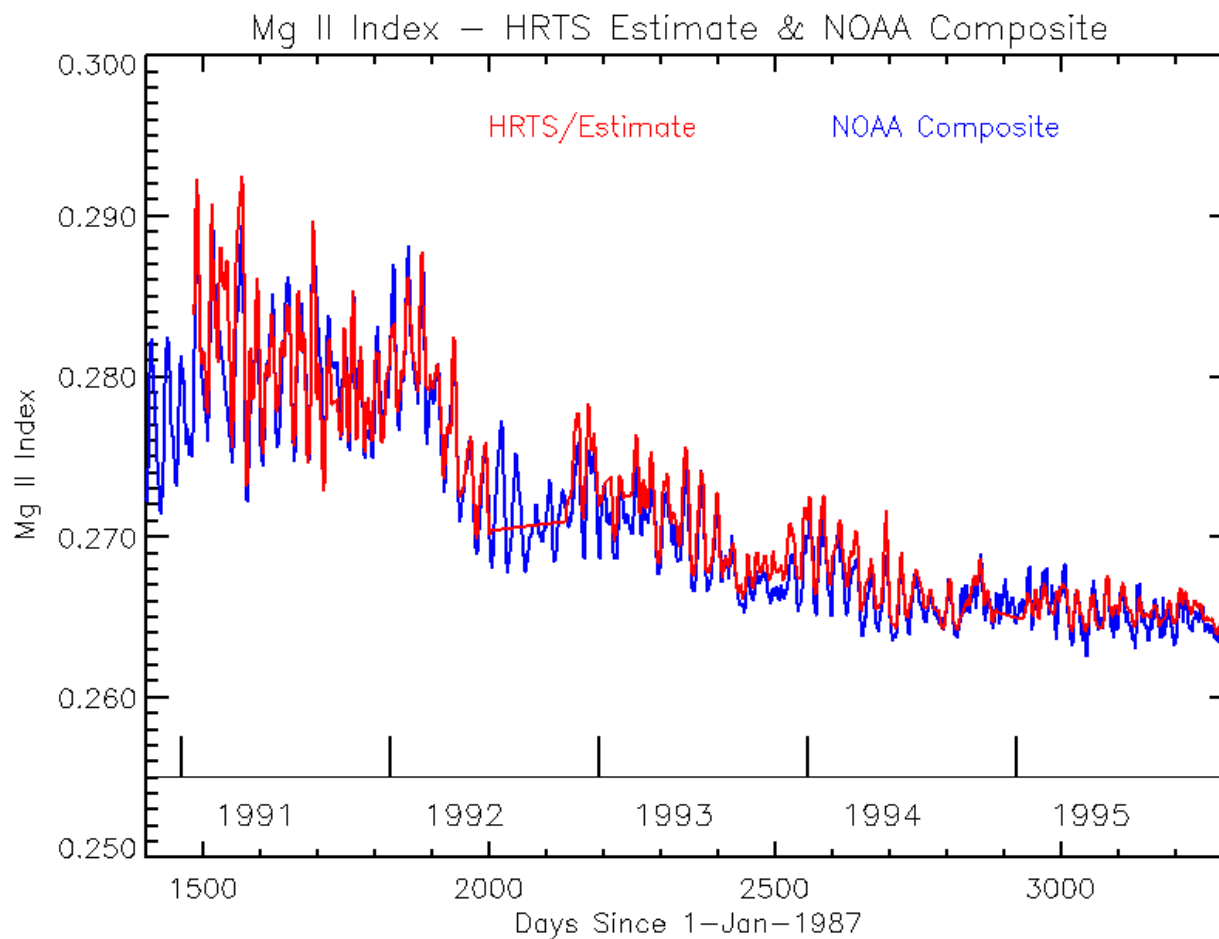
## Input Spectra



# Overview of Irradiance Model & Results



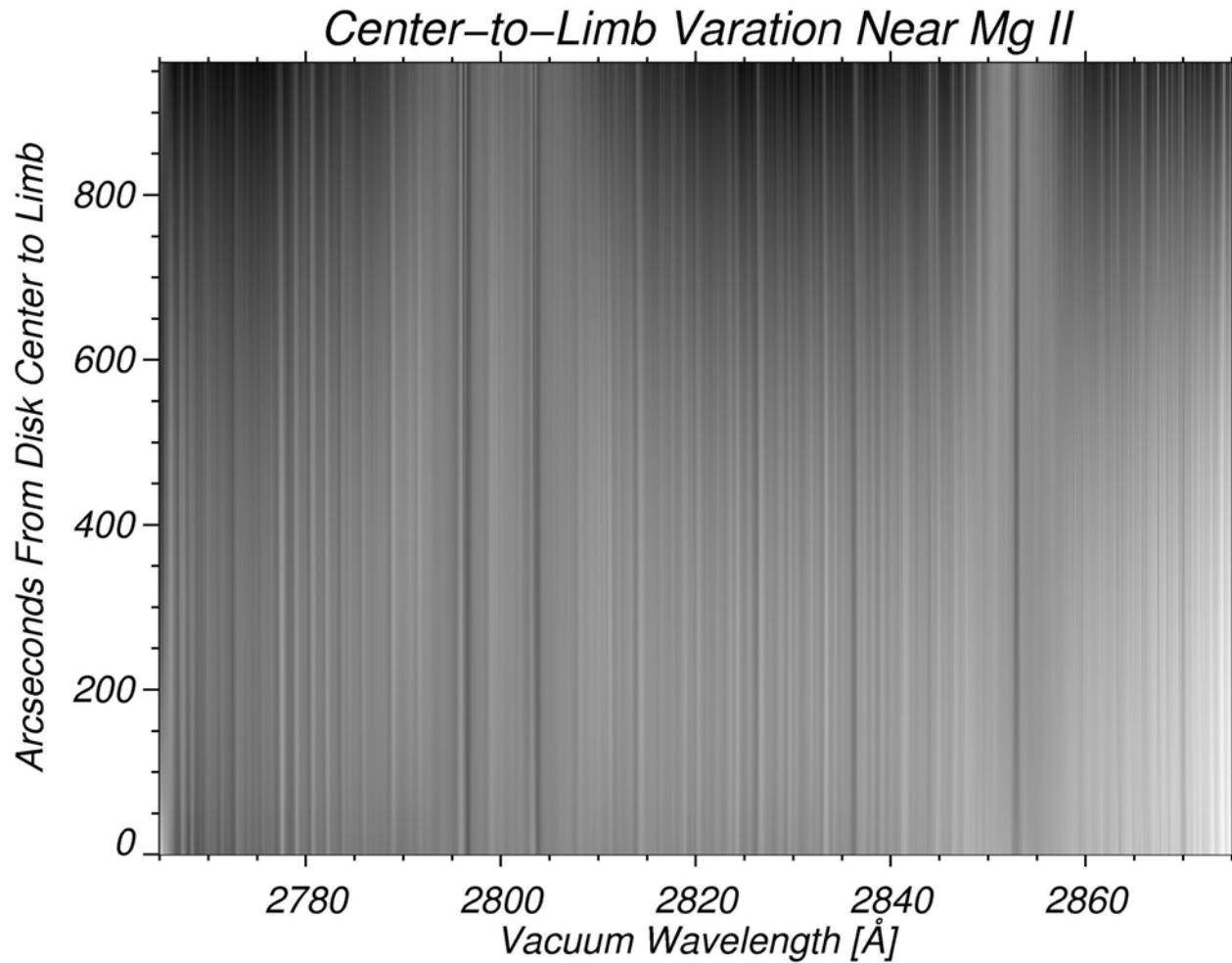
# Overview of Irradiance Model & Results



# Previous Results from HRTS-9

- The center-to-limb variation is derived from a quiet sun spectrogram measured by HRTS-9.
- The slit was parallel to the solar equator with one end near disk center and the other end near the limb.
- Polynomials were fit to observations at each wavelength interval ( $\sim .12 \text{ \AA}$ ).
- CLV Curves impact calibration of HRTS and SKYLAB spectral observations

# Previous CLV Results from HRTS-9

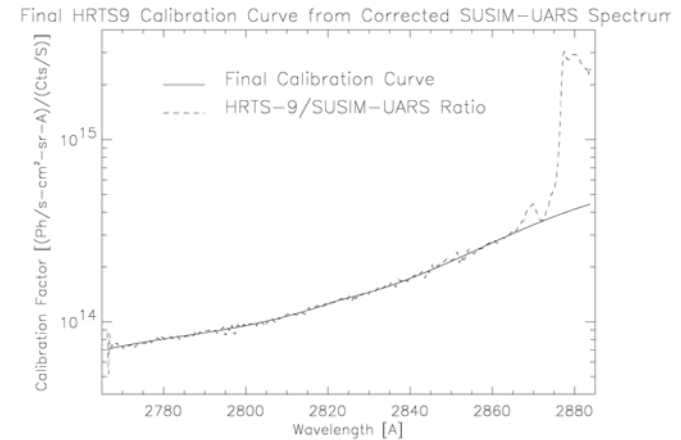
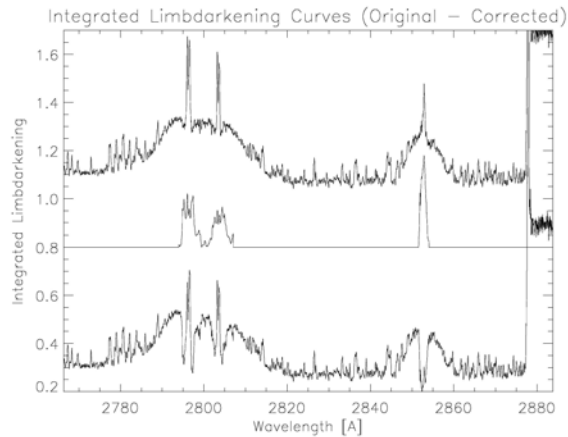
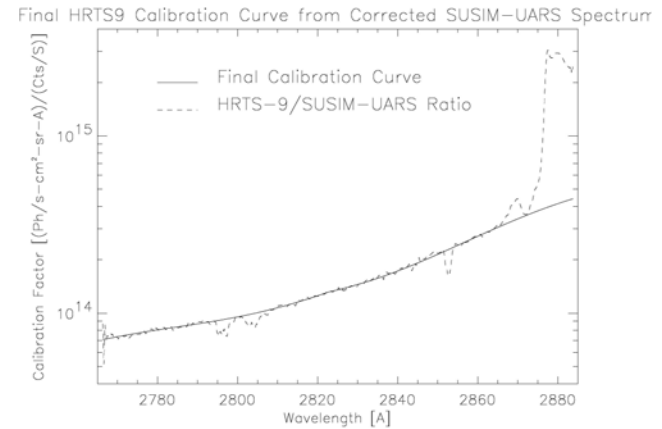
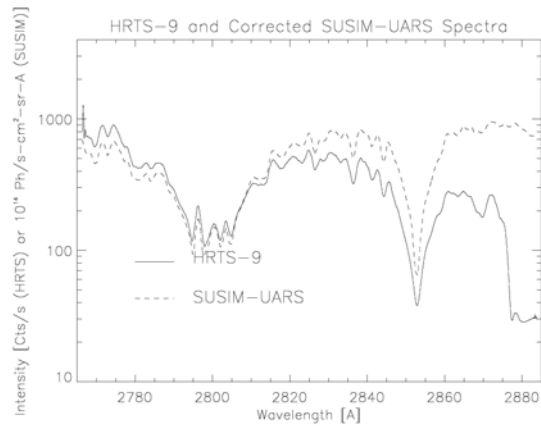


# Previous Calibration Results from HRTS-9

## Absolute intensity calibration:

- Compare estimated quiet sun spectra and observed full disk irradiance spectra with no active component.
- The initial calibration shows a residual that is used to modify the integrated center-to-limb (CLV) curve.
- The new integrated curve is used to modify initial CLV.
- Final CLV array yields the modified integrated CLV curve shown below.
- Likely due to exposure time uncertainties.
- Units of  $\text{mW}/\text{m}^2 \text{ nm}$ .

# Previous Calibration Results from HRTS-9



# Scanning Photographic SKYLAB Data

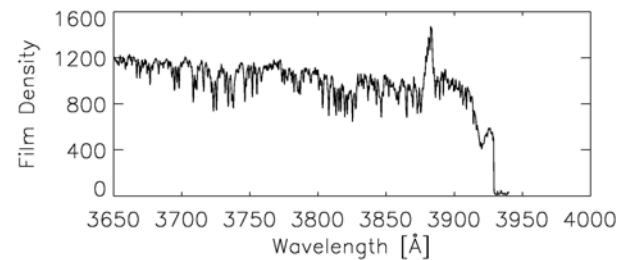
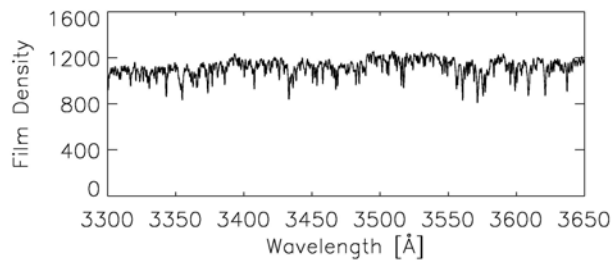
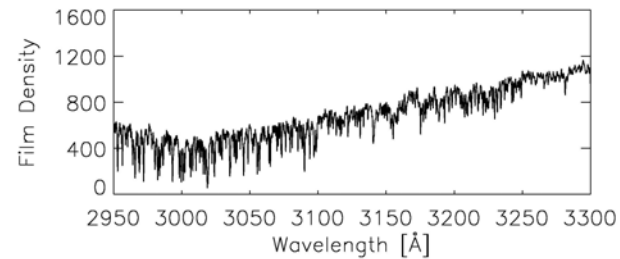
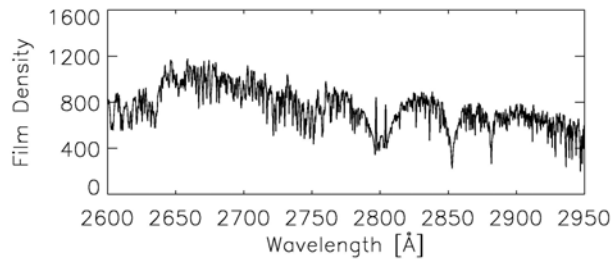
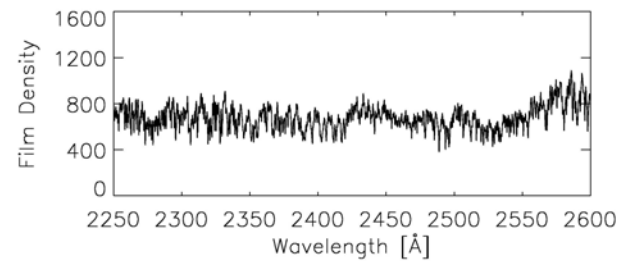
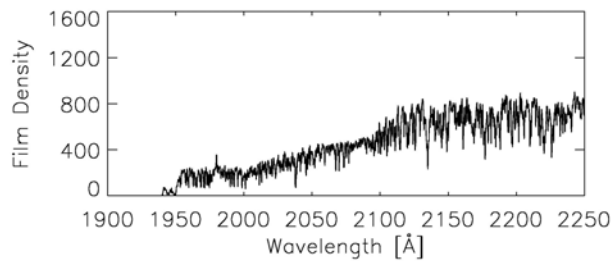
- Current spectra transferred from film to electronic form using commercial flat-bed scanner (UMAX PL3000)
- Pixel size – 3048 dots-per-inch
- Each SKYLAB plate contains 8 spectra
- Scan time for each plate is several hours
- Spectra saved as TIFF files and transferred to FITS format in IDL

# Present Results from SKYLAB

- SKYLAB CLV requires spectra observed at positions from disk center to the limb.
- Re-evaluated data previously analyzed at low resolution by Moe and Malone (1977).
- Disk center spectra added to current data.
- Resolution of spectra  $\sim .025\text{\AA}$ ; M&M  $\sim 10\text{\AA}$ .
- Spectra at Short ( $\sim 980\text{-}2000\text{\AA}$ ) and Long ( $2000\text{-}4000\text{\AA}$ ) wavelengths scanned.

# Present Results from SKYLAB

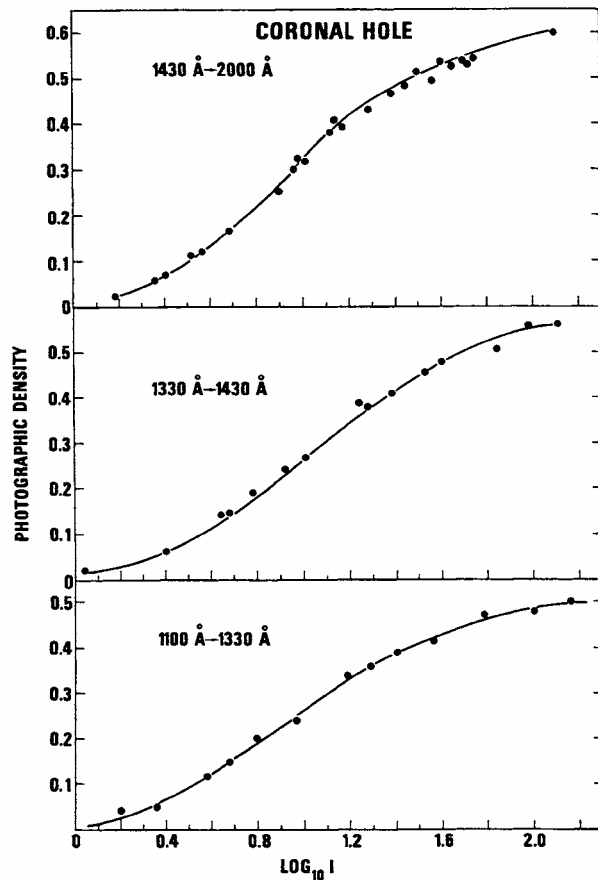
## Active Sun Spectrum – 2000 - 4000Å



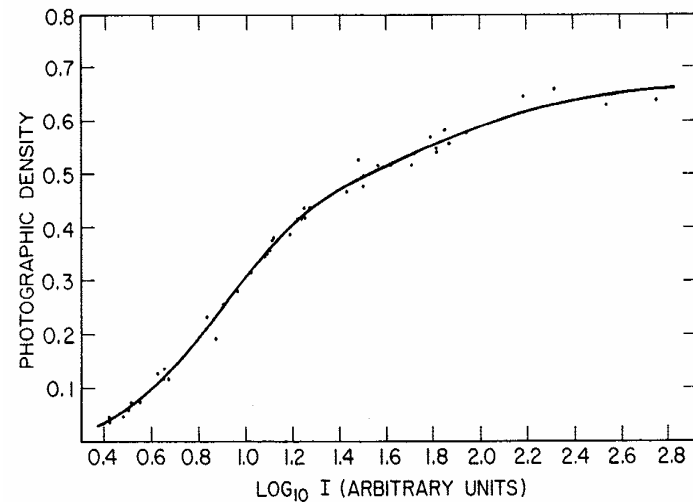
# Present Results from SKYLAB

## Film Correction Curves for Short and Long Wavelength Ranges

### Short Wavelength Range



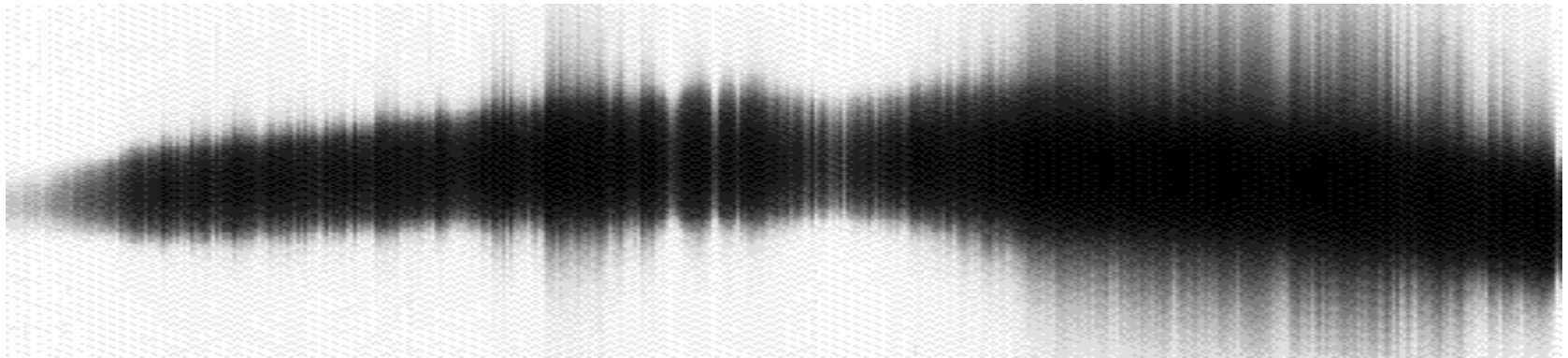
### Long Wavelength Range



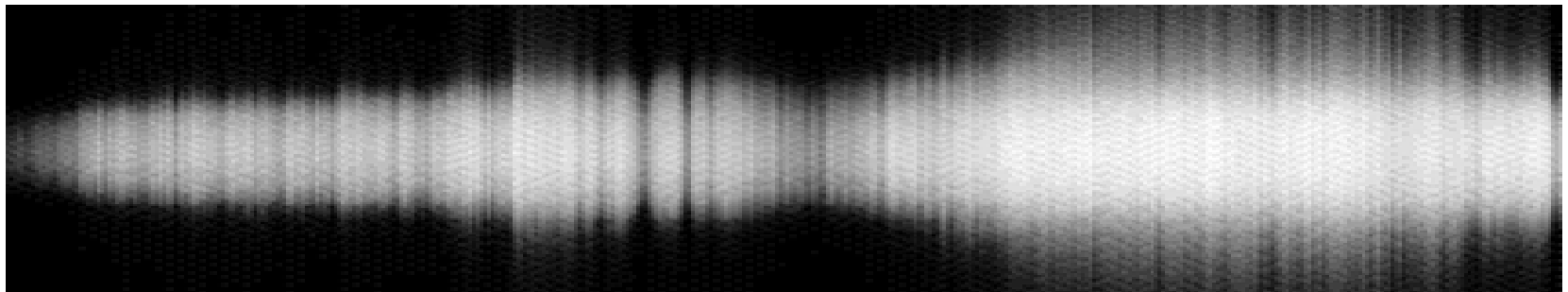
Film corrections require 3 curves for short wavelengths but only 1 for long wavelength range.

# Present Results from SKYLAB

Image of SKYLAB Spectrum  
Before Straightening

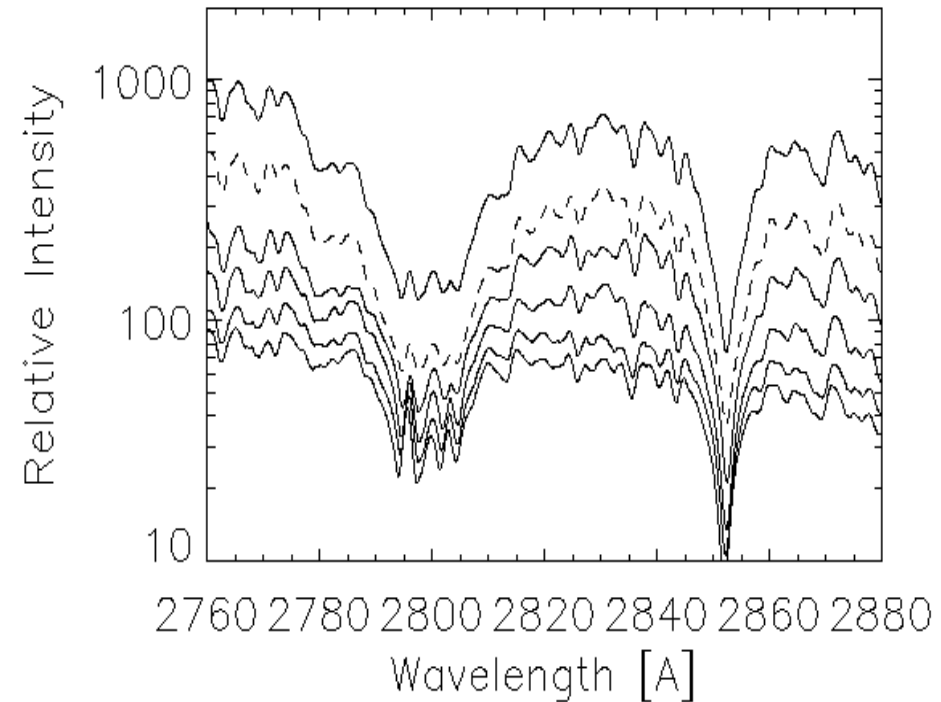
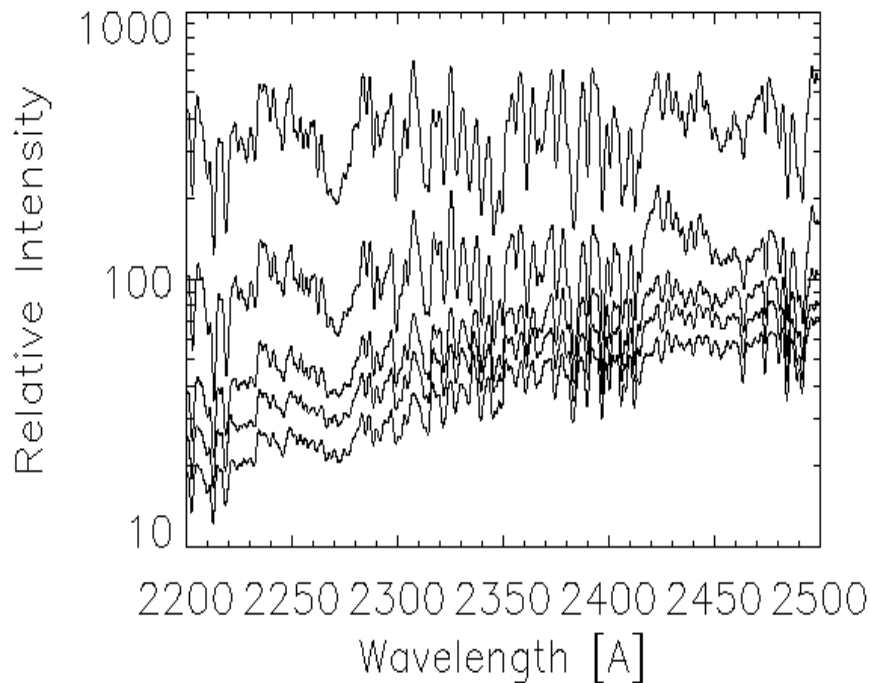


After Straightening



# Present Results from SKYLAB

## Center-to-Limb Variation From SKYLAB Data



$\mu = 1.00, 0.73, 0.32, 0.16, 0.09$

# Future Work

- Extend SKYLAB results to wavelengths below 2000 Å.
- SKYLAB data extends from 2000 Å down to ~1200 Å and below (minimum ~ 980 Å).
- Using Mg II index as proxy it is possible to include the EUV (minimum ~304Å).
- Using recently digitized Ca II K images from Mt Wilson Observatory we have proposed to extend irradiance model from 4000 to 300Å and generate estimated spectra for the 1915 to 1984 time period.

# Conclusions

## **Center-to-Limb Variation is:**

- Required for absolute calibration of film.
- Required for estimate of long-term solar spectra.
- Extremely important to understanding irradiance variability in the UV and EUV.
- Important wavelengths for terrestrial atmosphere: greatest variability and impact.

## **Use of Film Data:**

- Film data presents difficulties but is an important resource. SKYLAB database contains ~ 6400 Spectra.