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71st International Astronautical Congress – The CyberSpace Edition

12-14 October 2020

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Relative Wavelength Calibration of the Full-sun Ultraviolet Rocket SpecTrograph (FURST)

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-- Introduction -- 2 -- 3 -- 4 -- 5

-- Sounding Rockets -- FURST -- Existing Spectra

- A modular platform for experimental optical instruments
  - CLASP, Hi-C, MaGIXS, etc. [1-6]
- Spectral imaging during a sub-orbital flight
- Flexible launch locations such as:
  - White Sands Missile Range, New Mexico
  - Poker Flats, Alaska
- Quick project turn-around
- Diverse & international group

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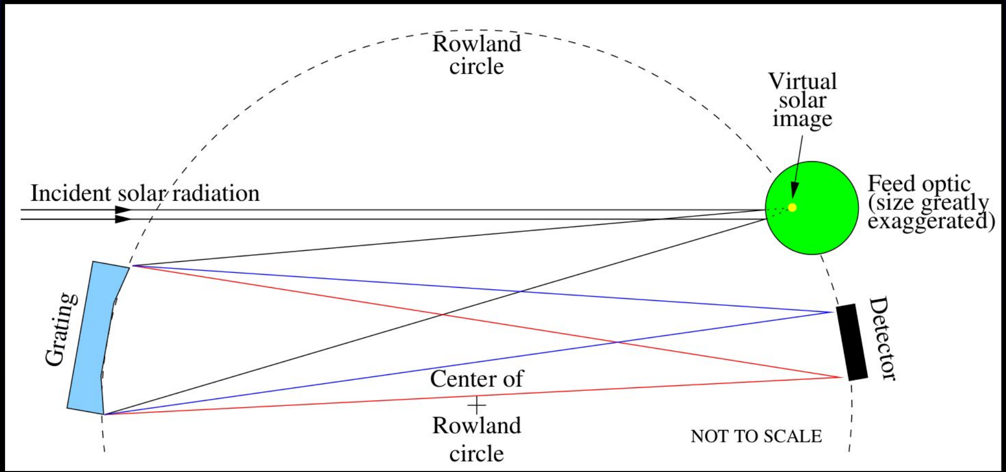
-- Sounding Rockets -- FURST -- Existing Spectra

- The Full-sun Ultraviolet Rocket SpecTrograph [7]
  - Will be able to directly compare our Sun's spectra with existing extra-solar data
- Uses a Rowland circle and 7 optical cylinders.
  - Each reflects ≈ 104 Å



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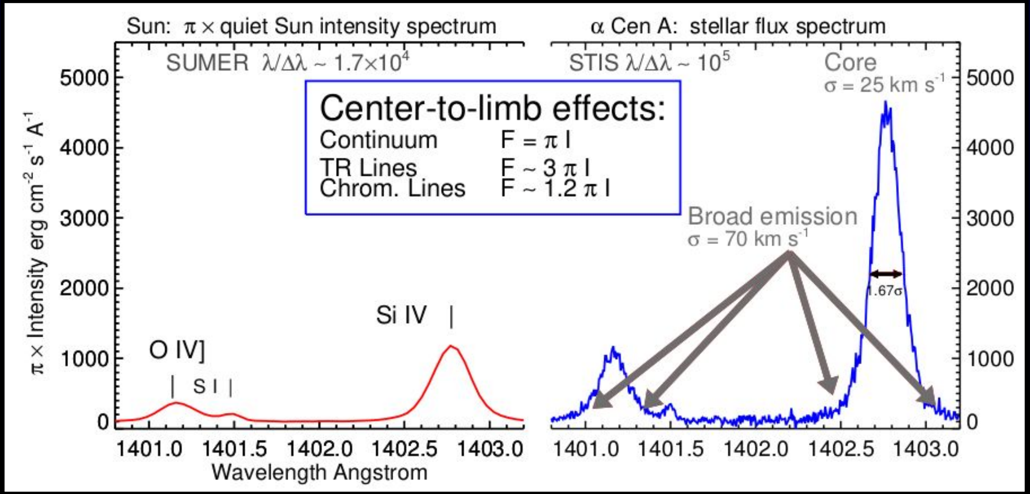
-- Introduction -- 2 -- 3 -- 4 -- 5

-- Sounding Rockets -- FURST -- Existing Spectra

- Limited range & resolution
- Example comparison [8]:
  - The Sun (SUMMER: $R \approx 10^4$)
  - Alpha Centauri A (STIS: $R \approx 10^5$)
- FURST goal is $R > 10^5$
  - (3 km/s Doppler-shift)



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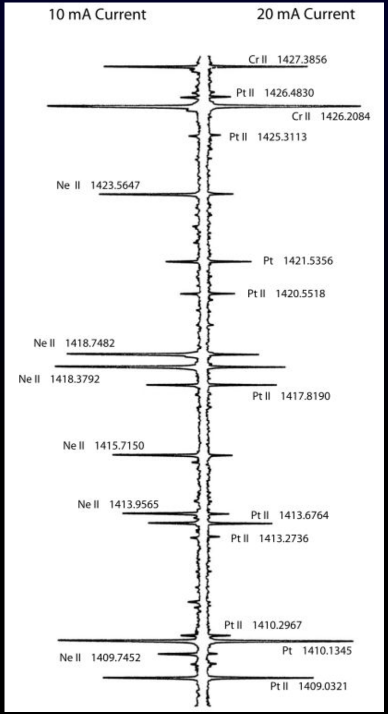
1 -- The Simulated Signal -- 3 -- 4 -- 5

-- Diagnostic Lamp -- Line-Spread Function -- Real Units

- Pt/Cr-Ne hollow cathode lamp signal
  - Sansonetti et al. 2004 [9]
  - Simulated at 20 mA current
  - Wavelength error of 0.002 Å
- Only a few of the most intense lines used for this simulation.
  - In the future, this will be done by hand-picking the 5 or so lines to be used for each channel, and carefully validating their locations and intensities.



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1 -- The Simulated Signal -- 3 -- 4 -- 5

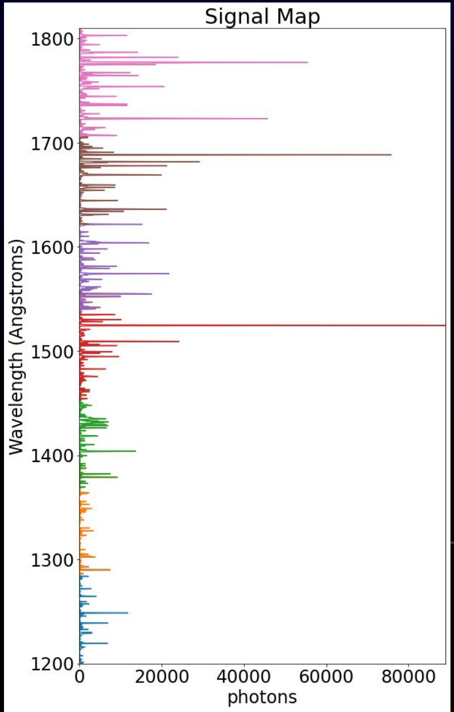
-- Diagnostic Lamp -- Line-Spread Function -- Real Units

- Data file gives locations and intensities
- Generate a Gaussian using:

$$I = (I_0 - I_b)\, e^{-\left(\frac{\lambda - \lambda_0}{2\sigma}\right)^2} + I_b$$

- Line-spread function varies
  - For now, we estimate it with a few experimental values:

$$\sigma_{width} = \begin{cases} 11.2 & \text{if} \quad \lambda = 1170 \\ 15.6 & \text{if} \quad \lambda = 1570 \\ 23.3 & \text{if} \quad \lambda = 1170 \end{cases}$$



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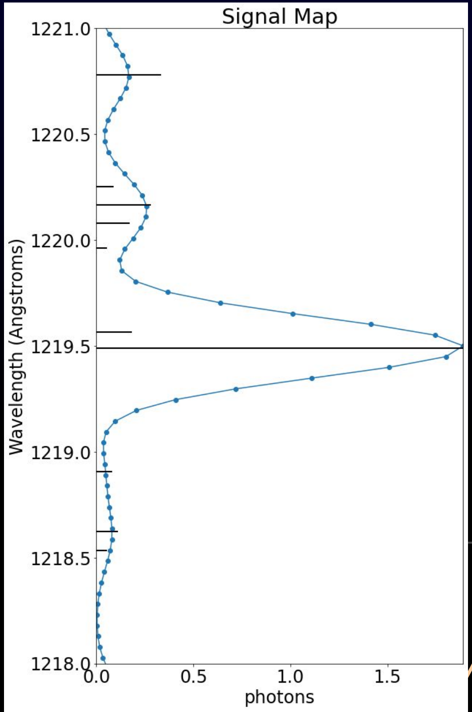
1 -- The Simulated Signal -- 3 -- 4 -- 5

-- Diagnostic Lamp -- Line-Spread Function -- Real Units

- We ensure the mapping of the signal onto discrete pixels in each range.
- Conversion process:

Arbitrary Units
→ Photons
→ Electrons
→ Data Numbers (DNs)

- We add noise with each step!



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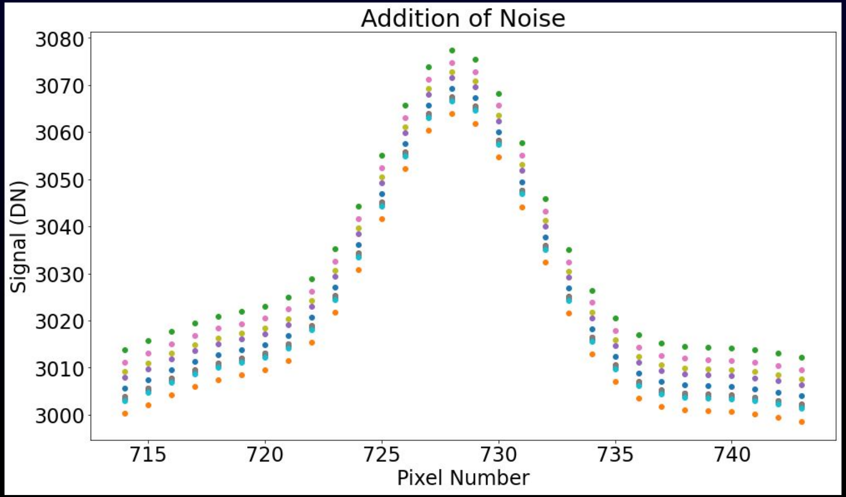
1 -- 2 -- Monte-Carlo Gaussian-Fitting -- 4 -- 5

-- Addition of Error -- Gaussian Fitting

- Fitting Process:
  - 1. Noise is added
  - 2. Fitting result is stored in a histogram
- Noise added:
  - Photon noise (Poisson)
  - Readout bias and noise (3000 ± 25 DN)
- Noise *not yet* added:
  - Effective Area, Vacuum Attenuation, Gain fluctuation during reading, etc.



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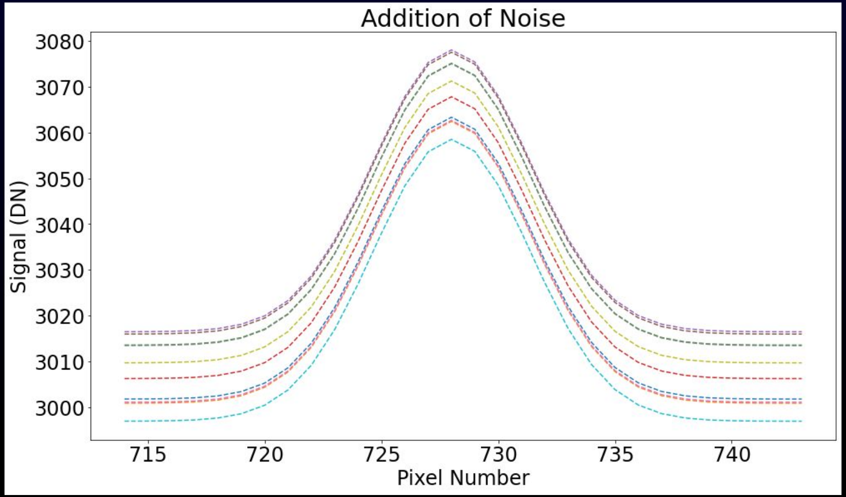
1 -- 2 -- Monte-Carlo Gaussian-Fitting -- 4 -- 5

-- Addition of Error -- Gaussian Fitting

- Fitting gives the peak location with sub-pixel resolution
  - Result is stored in a histogram
  - We us the mean and standard error of the mean of these histograms



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1 -- 2 -- 3 -- The Wavelength Function -- 5

-- Orthogonal Distance Regression -- Propagation of Error

- Nonlinear ODR with user-supplied 2nd order polynomial
  - λ: wavelength and given error (from lamp data)
  - x: mapped pixel value with error (from simulation)

Cylinder #	$\Delta\lambda_0$	ΔA	ΔB
1	0.04408	8.76E-05	3.45E-08
2	0.01279	2.88E-05	1.41E-08
3	0.14301	38.8E-05	21.8E-08
4	0.06298	7.87E-05	2.50E-08
5	0.03362	6.87E-05	2.99E-08
6	0.04550	8.87E-05	3.78E-08
7	0.06204	12.7E-05	5.65E-08
Mean	0.05772	12.4E-05	5.95E-08

$$\lambda = (\lambda_0 \pm \Delta\lambda_0) + (A \pm \Delta A) \cdot x + (B \pm \Delta B) \cdot x^2$$

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1 -- 2 -- 3 -- The Wavelength Function -- 5

-- Orthogonal Distance Regression -- Propagation of Error

- Error propagation gives:

$$\Delta\lambda = \sqrt{\Delta\lambda_0^2 + \Delta A^2 \cdot |x| + \Delta B^2 \cdot x^2}$$

- Converting to Resolution in doppler shift velocity:

$$R = \frac{\lambda}{\Delta\lambda} = \frac{c}{\Delta v} \implies \Delta v = c\frac{\Delta\lambda}{\lambda}$$

- Using pixel values 0 - 2047 for each:
  - Δv ≈ 12 km/s
  - *Δv range ≈ 3-31 km/s*

Range (Å)	$\Delta\lambda$ (Å)	Δv (km/s)
1200.0 - 1304.0	0.044 - 0.044	11.01 - 10.18
1284.3 - 1388.3	0.013 - 0.013	2.99 - 2.78
1368.7 - 1472.7	0.143 - 0.144	31.32 - 29.33
1453.0 - 1557.0	0.063 - 0.063	12.99 - 12.15
1537.3 - 1641.3	0.034 - 0.034	6.56 - 6.17
1621.7 - 1725.7	0.046 - 0.046	8.41 - 7.94
1706.0 - 1810.0	0.062 - 0.062	10.90 - 10.32
Mean	0.05786	11.65

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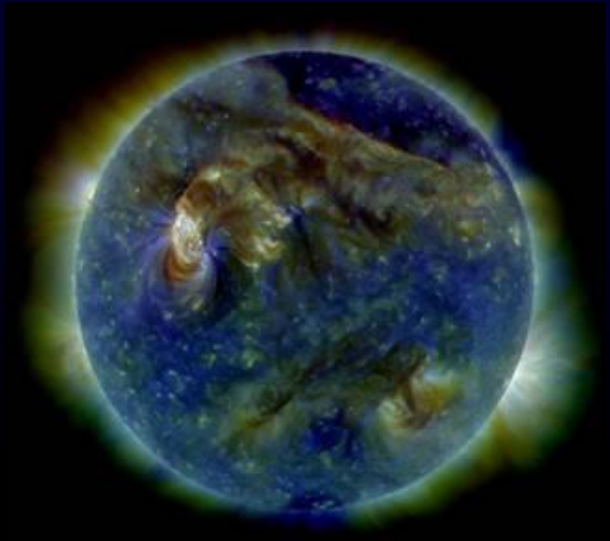
1 -- 2 -- 3 -- 4 -- Results and Conclusions

-- Summary -- Future Work

1. Simulated a diagnostic lamp signal, accounting for noise.
2. Developed a method for deriving the pixel-mapping function.
3. Estimated the propagation of error and expected resolution.
   - 12 km/s is achievable
   - 3 km/s may be possible
   - Will require additional research and advanced calibration techniques

Sun in UV (credit: NASA/SDO)



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1 -- 2 -- 3 -- 4 -- Results and Conclusions

-- Summary -- Future Work

- Measuring the actual line-spread function
- Experimental calibration of the diagnostic lamp
  - Understanding of wavelengths and intensities
  - Testing reliable lines in each cylinder range.
- Effective area calibration
  - New collimator build
- Gain fluctuation is significant.
  - We aim to diminish this through an Fe55 source used as a “control.”

MSFC Collimator (credit: NASA)

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References

[1] S Tsuneta, K Ichimoto, Y Katsukawa, S Nagata, M Otsubo, T Shimizu, Y Suematsu, M Nakagiri, M Noguchi, T Tarbell, et al. The Solar Optical Telescope for the Hinode Mission: an Overview. *Solar Physics*, 249(2): 167–196, 2008.

[2] Ryouhei Kano, Takamasa Bando, Noriyuki Narukage, Ryoko Ishikawa, Saku Tsuneta, Yukio Katsukawa, Masahito Kubo, Shinnosuke Ishikawa, Hirohisa Hara, Toshifumi Shimizu, et al. Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP). In *Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, volume 8443, page 84434F. International Society for Optics and Photonics, 2012.

[3] Shinnosuke Ishikawa, Masahito Kubo, Yukio Katsukawa, Ryouhei Kano, Noriyuki Narukage, Ryohko Ishikawa, Takamasa Bando, Amy Winebarger, Ken Kobayashi, Javier Trujillo Bueno, et al. CLASP/SJ Observations of Rapid Time Variations in the Lyα Emission in a Solar Active Region. *The Astrophysical Journal*, 846(2): 127, 2017.

[4] Ken Kobayashi, Amy R Winebarger, Sabrina Savage, Patrick Champey, Peter N Cheimets, Edward Hertz, Alexander R Bruccoleri, Jorg Scholvin, Leon Golub, Brian Ramsey, et al. The Marshall Grazing Incidence X-ray Spectrometer (MaGIXS). In Space Telescopes and Instrumentation 2018: Ultraviolet to Gamma Ray, volume 10699, page 1069927. *International Society for Optics and Photonics*, 2018.

[5] Ken Kobayashi, Jonathan Cirtain, Amy R Winebarger, Kelly Korreck, Leon Golub, Robert W Walsh, Bart De Pontieu, Craig DeForest, Sergey Kuzin, Sabrina Savage, et al. The HIgh-resolution Coronal imager (HI-C). *Solar Physics*, 289(11): 4393–4412, 2014.

[6] Amy R Winebarger, Bart De Pontieu, Chun Ming Mark Cheung, Juan Martinez-Sykora, Viggo H Hansteen, Paola Testa, Leon Golub, Sabrina L Savage, Jenna Samra, and Katharine Reeves. Unfolding Overlappogram Data: Preparing for the COOL-AID Instrument on HI-C Flare. *AGUFM*, 2019: SH33A–06, 2019.

[7] Charles Kankelborg, Philip Judge, Amy Winebarger, Ken Kobayashi, and Roy Smart. VUV Spectroscopy of the Sun as a Star. In Solar Physics Department. *Montana State University*, 2017.

[8] TN Woods, FG Eparvier, R Hock, AR Jones, D Woodraska, D Judge, L Didkovsky, J Lean, J Mariska, H Warren, et al. Extreme ultraviolet Variability Experiment (EVE) on the Solar Dynamics Observatory (SDO): Overview of Science Objectives, Instrument Design, Data Products, and Model Developments. In *The solar dynamics observatory*, pages 115–143. Springer, 2010.

[9] Craig J Sansonetti, F Kerber, Joseph Reader, and Michael R Rosa. Characterization of the Far-Ultraviolet Spectrum of Pt/Cr-Ne Hollow Cathode Lamps as Used on the Space Telescope Imaging Spectrograph on board the Hubble Space Telescope. *The Astrophysical Journal Supplement Series*, 153(2): 555, 2004.

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