A *FURST* look at the VUV Sun as a Star

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Motivation

The solar VUV spectrum (~100-200 nm) is not as well known as that of stars observed by the Hubble Space Telescope. What could we learn from a full-Sun VUV spectrum?

1. Sun as a star
   - Heating of solar and stellar chromospheres
   - Detailed comparison of solar and HST line profiles
   - Small-scale magnetic reconnection and dissipation
2. Solar system and heliospheric science
   - Resonant absorption in atmospheres
   - planets, moons, comets (orbital doppler shift)
3. First step: sounding rocket flight!

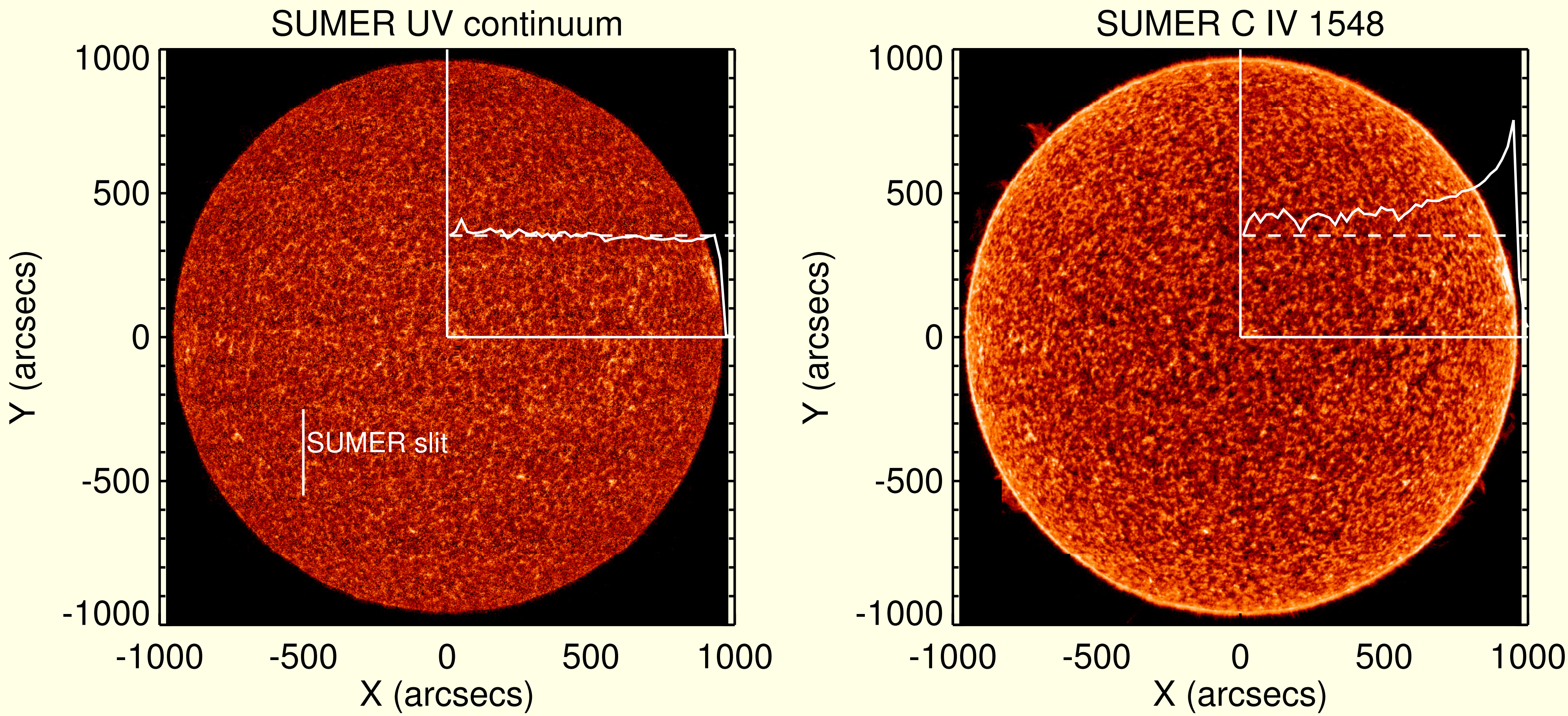
Can we use existing data?

Some radiometric solar (E)UV spectral irradiance datasets

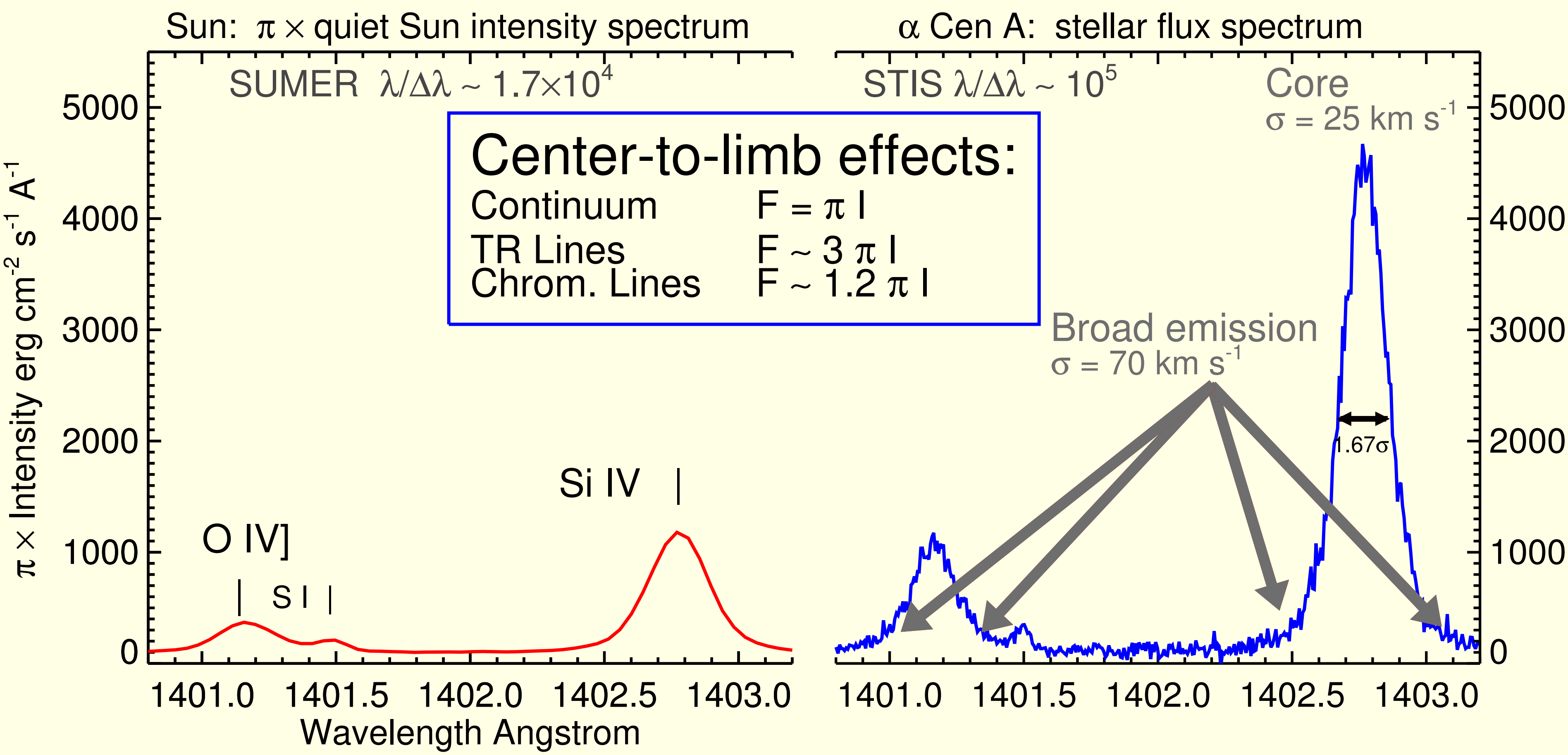
Instrument	Dates	λ nm	Smallest $\Delta\lambda$ nm
AE C-E	1974-1981	14-185	0.1
SME	1982-1989	H Lα 121.5	1
UARS/SOLSTICE	1991-1994	120–420	0.12 ($\mathcal{R} = 1000$)
UARS/SUSIM	1991-2005	115-410	0.15
TIMED/SEE	2002$\rightarrow$	0-200	0.1
SDO/EVE	2010$\rightarrow$	0.1-105	0.1
FURST	**2021**$\rightarrow$	**112-200**	$\leq$**0.01** **(**$\mathcal{R}$ $\geq$**10,000)**

Can we use existing data?

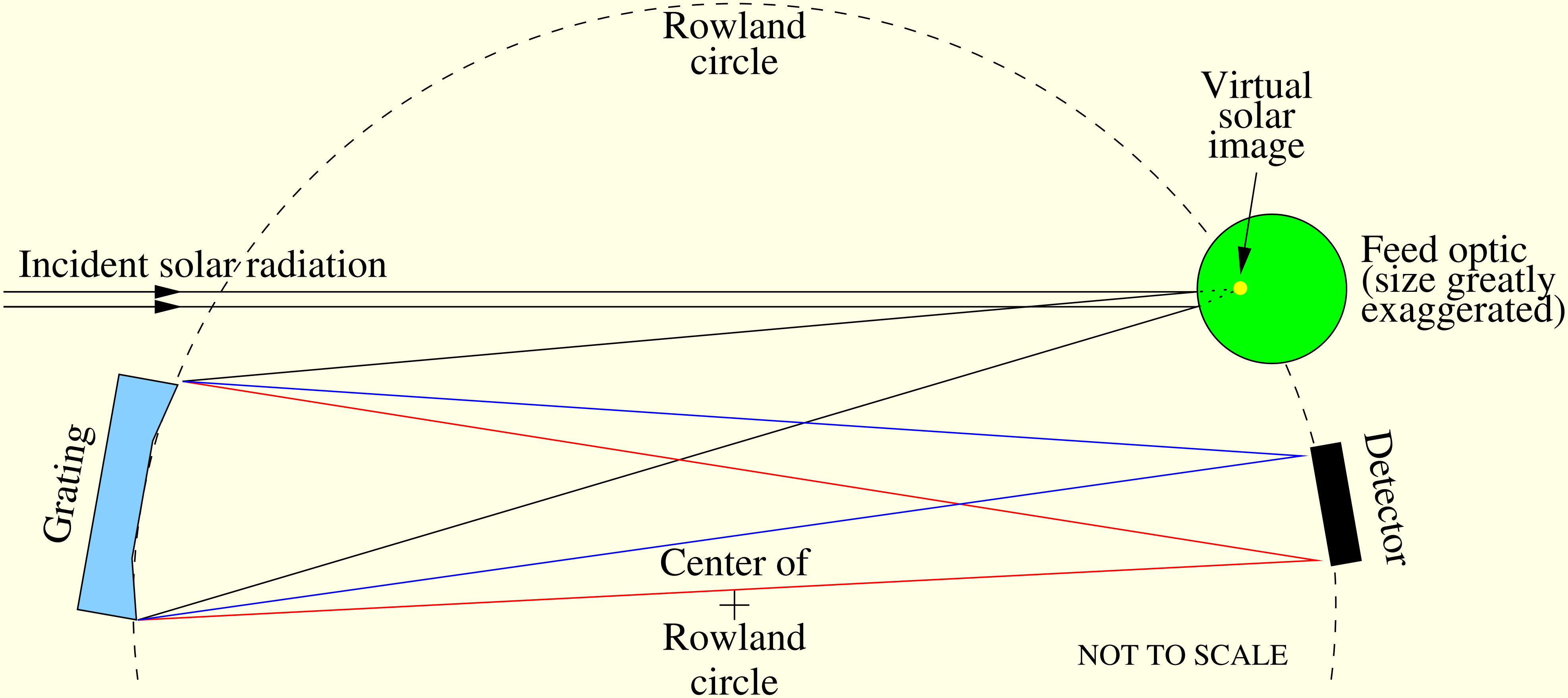
Center-to-limb effects, and other nonuniformities, prevent the inference of full-Sun spectra from high resolution data.



Can we use existing data?



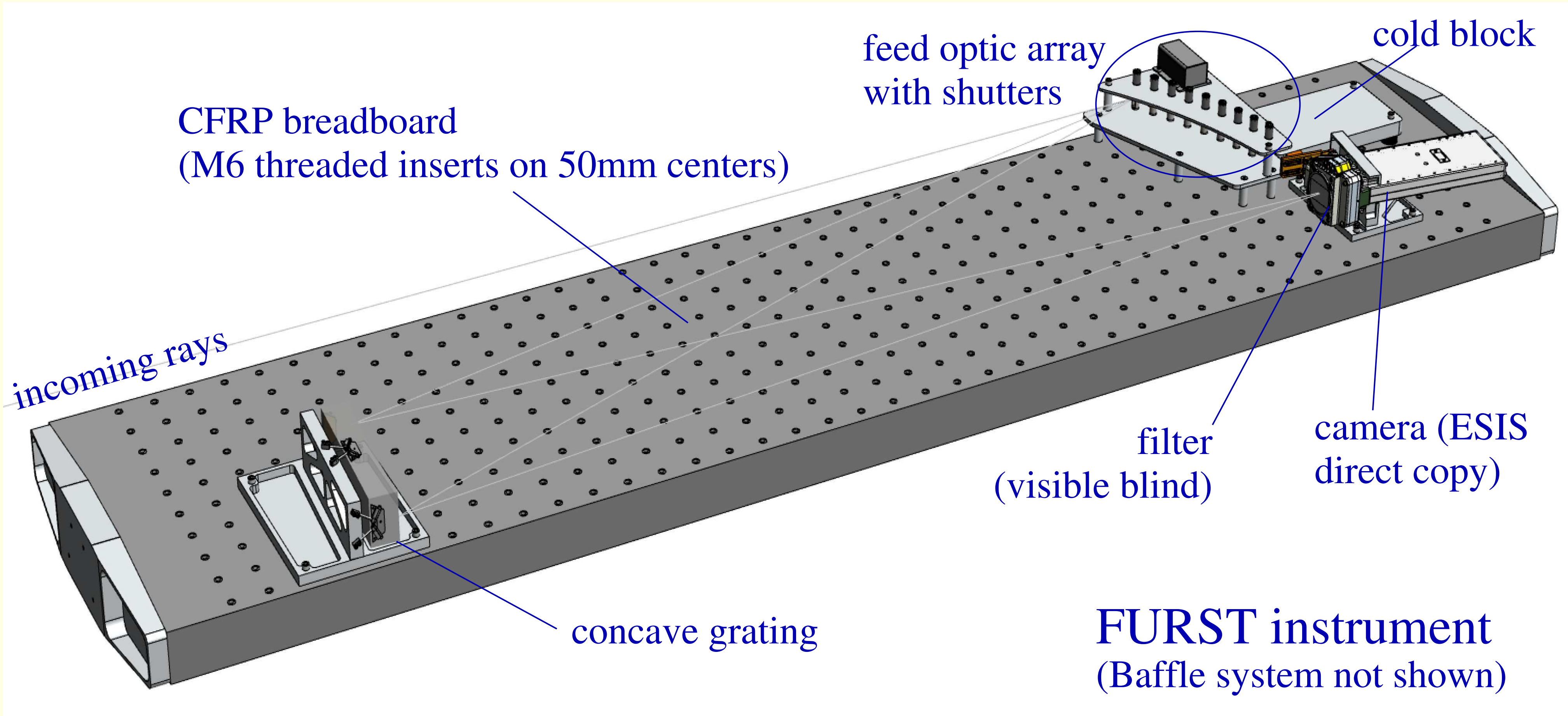
Optical Concept



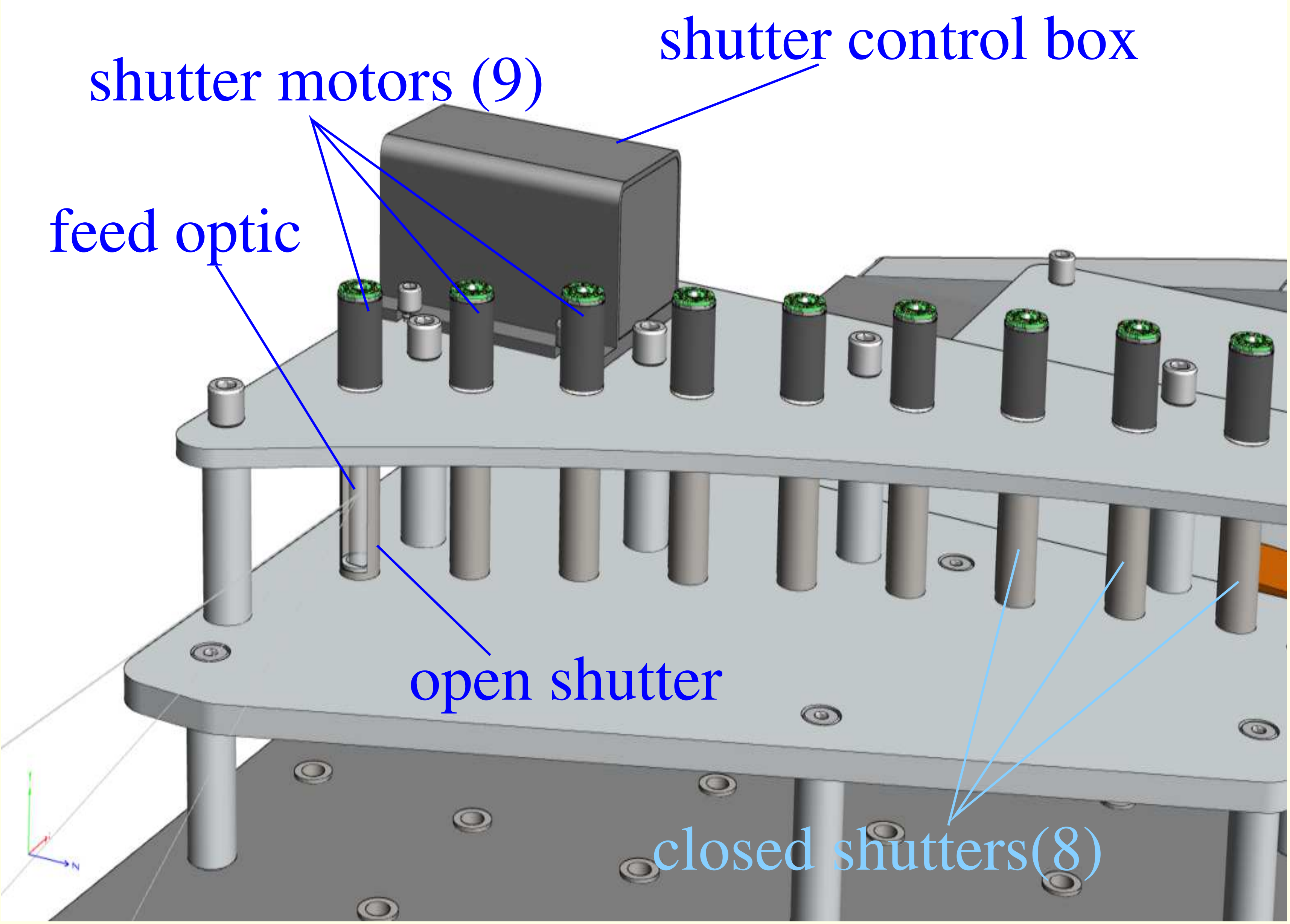
The position of the virtual image along the Rowland Circle determines the wavelength falling at detector center.

FURST

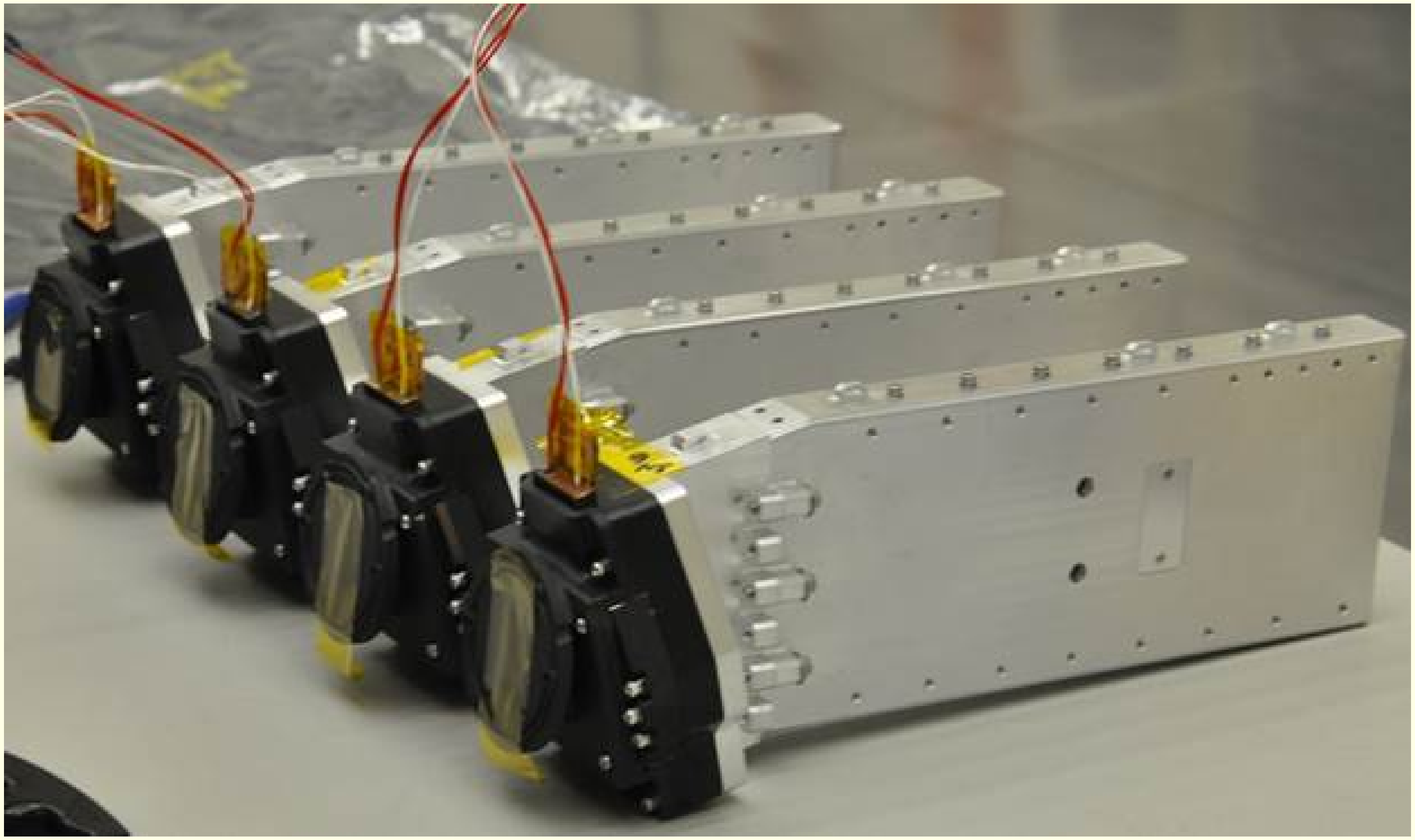
Full-sun Ultraviolet Rocket SpecTrometer



Feed Optics and Shutters



Camera and Avionics



MSFC will provide the $FURST$ camera, a direct copy of the ESIS design. $FURST$ will use the ESIS avionics and EGSE.

Spectrometer Performance

Full wavelength range	112-200	nm
Single exposure wavelength range	10.4	nm
Spectral sampling interval	5.06	pm
Effective resolving power, $\mathcal{R}$	$> 2 \times 10^4$	$\lambda/\Delta\lambda$
Exposure duty cycle (shutter limited)	> 99	%
Signal-to-noise (150 nm continuum)	> 200	CBE

$FURST$ meets or exceeds all science requirements.

Calibration

1. NIST SURF-III Beamline 2*
   - End-to-end radiometric sensitivity
   - Spectral irradiance known to $< 1\%$

2. CLASP calibration section
   - Wavelength calibration
   - Instrumental linewidth (LSF)
   - Monitor stability of throughput
   - Lab and deployment to WSMR

*(Arp et al., 2011)

Summary & Conclusions

- *FURST* will be first to observe the full sun VUV spectrum (∼100-200 nm) at $\mathcal{R} > 10^4$.
- There are many applications:
  - Atmospheric and climate science
  - Solar system science
  - Solar and stellar physics
- The *FURST* rocket has been selected for funding. We are spinning up the program!
- The future:
  - Rocket launch late 2021
  - Propose future flights
  - Propose satellite instrument (small, low power)

Additional Slides

Abstract

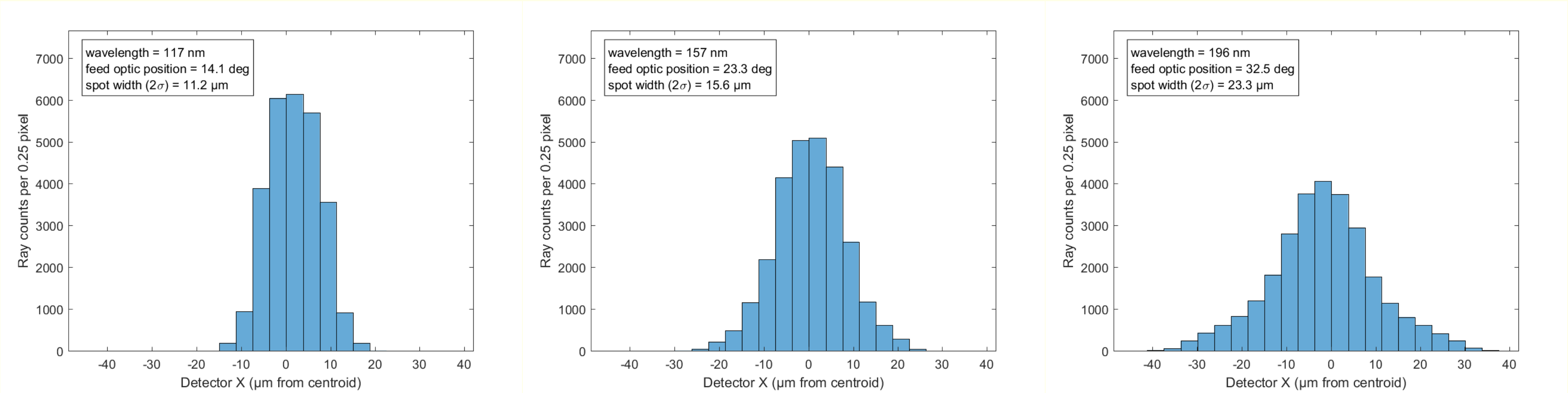
Hubble Space Telescope spectra for Sun-like stars are of such quality that we now know the input of radiation from α Cen A to our solar system far better than that of the Sun. We have therefore proposed the Full-Sun Ultraviolet Rocket Spectrometer (FURST) to obtain the first moderate resolution ($R > 10^4$), radiometrically calibrated VUV spectrum of the Sun-as-a-star. Our immediate science goal is to understand better the processes of chromospheric and coronal heating. The solar spectrum we obtain will enable us to understand the interaction of solar UV radiation with solar system bodies, the nature of magnetic energy dissipation as a Sun-like star evolves, and the dependence of magnetic activity on stellar mass and metallicity. We present the instrument design, scientific prospects, and broader impacts of the mission.

Requirements

Science	Driver	Measurement Requirement
Sun-as-a-star, heliospheric and solar system physics	Solar VUV spectral irradiance	Full solar disk observation with VUV spectrometer
Detailed comparisons of solar and HST spectra	HST UV radiometry $\pm 5\%^*$ STIS§/COS $\mathcal{R} = \lambda/\Delta\lambda \approx 2.5 \times 10^4$ UV wavelengths > 115 nm	Radiometry $\pm 5\%$ $\mathcal{R} \geq 2 \times 10^4$ $\lambda_{min} = 115$ nm
Detect small-scale magnetic reconnection and dissipation (explosive events, microflares)	Distinguish broad components of strong lines from continuum	SNR > 20 in 150 nm continuum
Resolve non-Gaussian line core profiles	TR core turbulent FWHM ~ 40 km/s Strong self-reversed lines H I, O I	$\mathcal{R} \approx 2 \times 10^4$
Resonant absorption in atmospheres of solar system bodies	orbital speeds (e.g. Europa) ± 13 km/s; sensitive to shifts < 0.1 linewidth†	absolute wavelength calibration ± 3 km/s
Quantify Lα/solar system plasma interactions	H Ly α flux $\approx 100\times$ others	λ121.6 nm unsaturated
Plasma diagnostic lines, strong lines	e.g. O I 115.2, C III 117.5, Si III 120.6, Lα 121.6, N V 123.8, C II 133.5, O IV 140.1, Si IV 139.3, C IV 154.8, He II 164.0, O III 166.0, Al II 167.0, Si II 180.7	cover wavelengths $115 < \lambda < 181$ nm

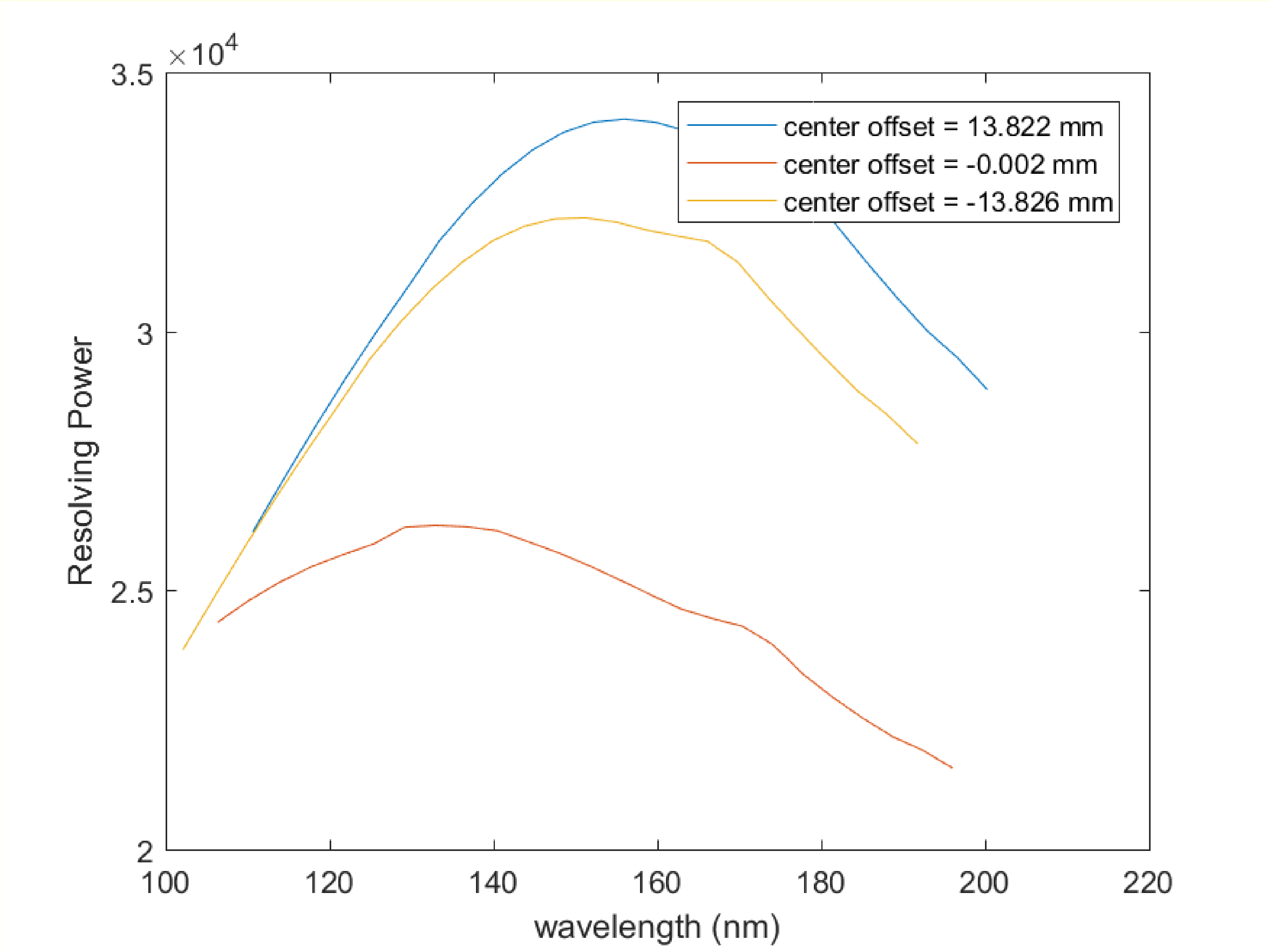
*Pagano et al. (2004); ‡(Ghavamian et al., 2009); §STIS data handbook, `http://www.stsci.edu/`

Spectrometer Raytrace



Histogrammed rays, summed vertically on the detector (perpenducular to dispersion). Rays from the full Sun are included.

Resolution $\sim 9\text{-}14$ km/s



References

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Ghavamian, P., Aloisi, A., Lennon, D., et al. 2009, Preliminary Characterization of the Post- Launch Line Spread Function of COS, Tech. rep.

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