OPAL – Optical Profiling of the Atmospheric Limb

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STEADE Mission

Storm Time Energy & Dynamics Explorers

- NASA Mission of Opportunity
- A constellation of secondary payloads on a string Iridium-NEXT payloads.

How do electromagnetic fields mediate the deposition of energy from solar storms into the Earth's atmosphere?

1. Temporal & spatial distribution of the electromagnetic energy input.
2. Temporal & spatial distribution of storm-driven electric fields in the ionosphere.
3. Temporal & spatial details of the thermospheric temperature response. (← OPAL)

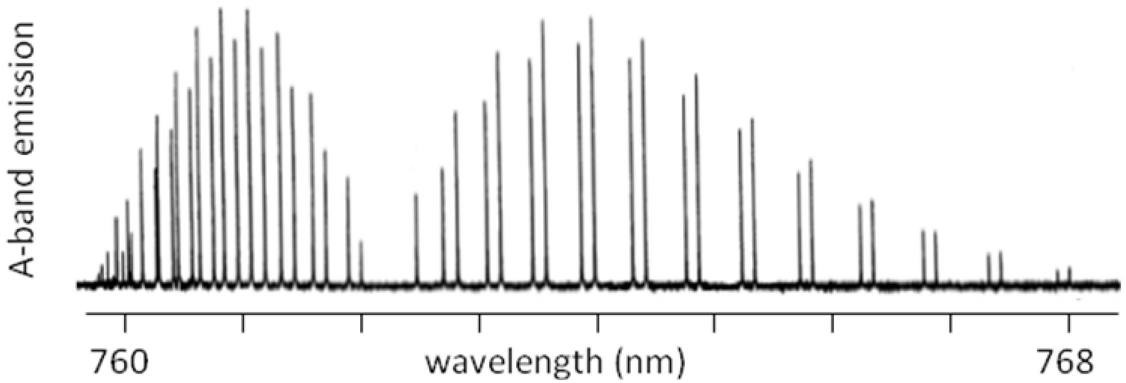
Satellite Platforms

- Iridium-NEXT telecommunications constellation: 11 satellites each in 6 near-polar orbits, 781 km altitude.
- Launch schedule 2015-2017. > 2 year mission.
- STEADE will add secondary payloads to the Iridium-NEXT satellites in one orbit.
- Forward mounted; fixed orientation w.r.t. Earth.
- 9-minute sampling period.

Oxygen A-band

Molecular Oxygen A-band emission.

- 760 – 768 nm
- day-time phenomenon, powered by solar ionization
- thermosphere is (relatively) bright, but still transparent, over the A-band



limb radiance

90 – 140 km

40 – 800 kR/nm

$3 - 70 \cdot 10^6 \ \frac{photons}{cm^2 \cdot s \cdot sr \cdot nm}$

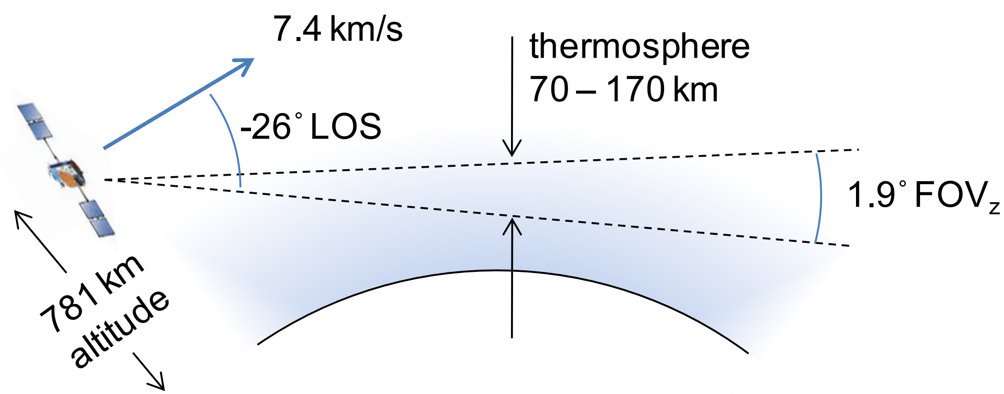
Temperature dependence.

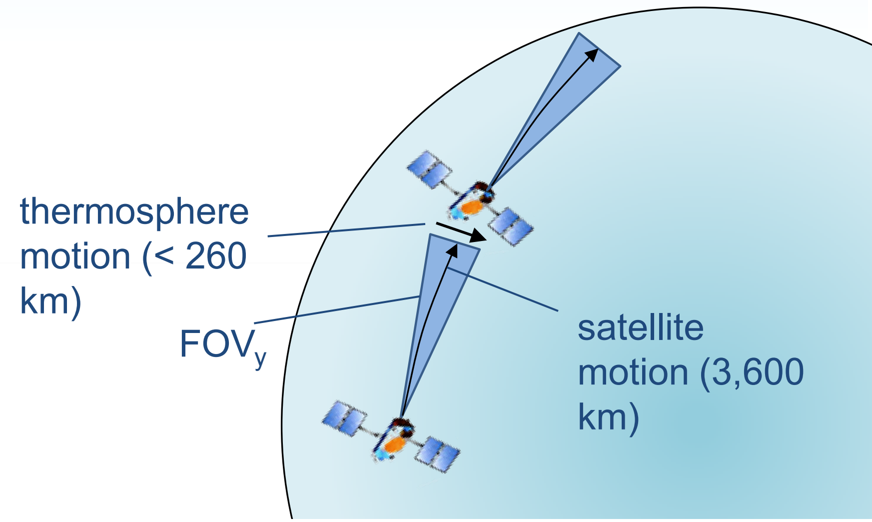
- band structure responds to the neutral temperature
- spectroscopic characterization of line shape (not radiometry) → thermosphere temperature

OPAL Hyperspectral Imager

OPAL – Optical Profiling of the Atmospheric Limb

- forward view through the limb





"Flash" hyperspectral imager

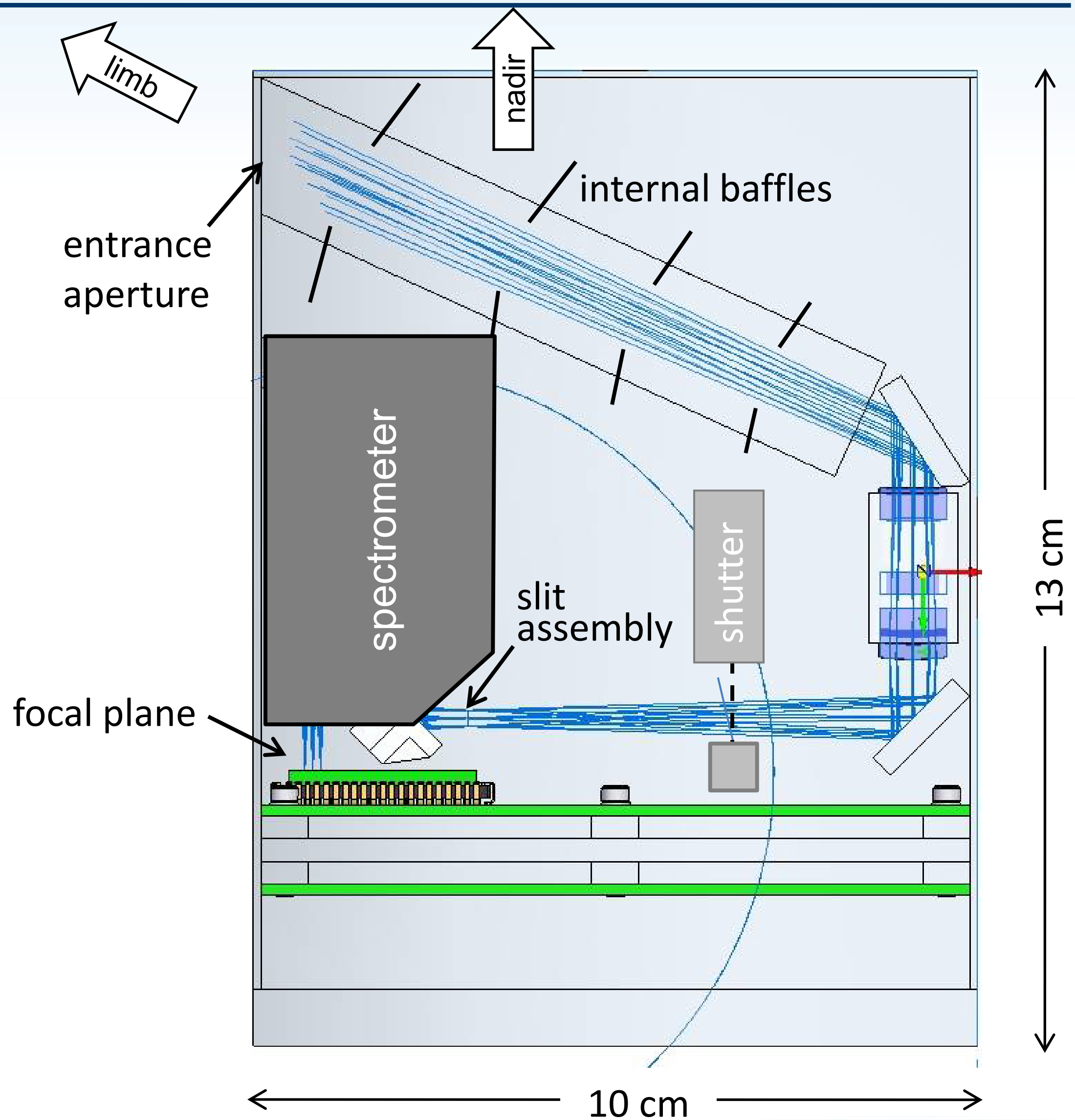
- resolve A-band spectral profile
- resolve vertical profile of the limb
  - deconvolve spectra to derive temperature vs. altitude)
- view multiple horizontal positions across the limb
  - match the atmospheric volume observed by preceding sensor

OPAL System Requirements

spectral resolution	< 0.6 nm
spectral band	759 – 769 nm
spatial resolution	< 5 km (1.7 mrad) vertical < 125 km (42 mrad) horizontal
field of view	> 50km (14 mrad) vertical > 500km(166 mrad) horizontal
sample period	< 18.5s
scene radiance	300 – 6,000 kRayleigh
sensitivity @ 100 km altitude	± 10K derived temperature > 50 SNR
sensitivity @ 140 km altitude	± 40K derived temperature > 12 SNR
form factor	CubeSat profile, no protrusion
operational constraints	no spacecraft maneuvers
data rate	< 10 kbit/s

Optical Design (initial concept)

- internal shade / baffles
- refractive fore-optics
- bandpass filter
- dispersive spectrometer
- multi-slit assembly
- area-array focal plane
- folded optical path
- 10cm x 10cm optical footprint



Trades:

- shutter vs. night-side calibration
- CCD vs CMOS focal plane
- spectrometer design

Multiple Slit Spectrometer

9 slits are imaged onto the focal plane

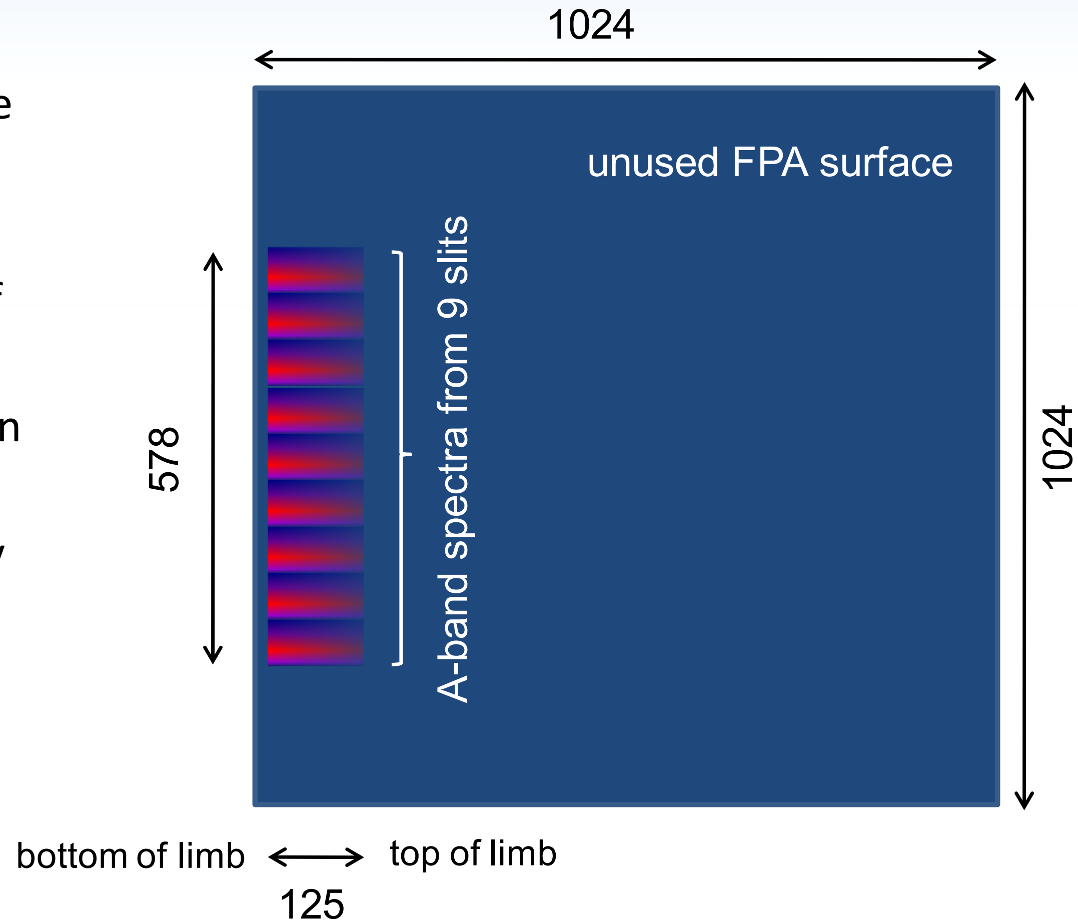
Each slit creates a spectral profile of one vertical slice through the limb.

A band-pass filter prevents overlap of the dispersed slit images.

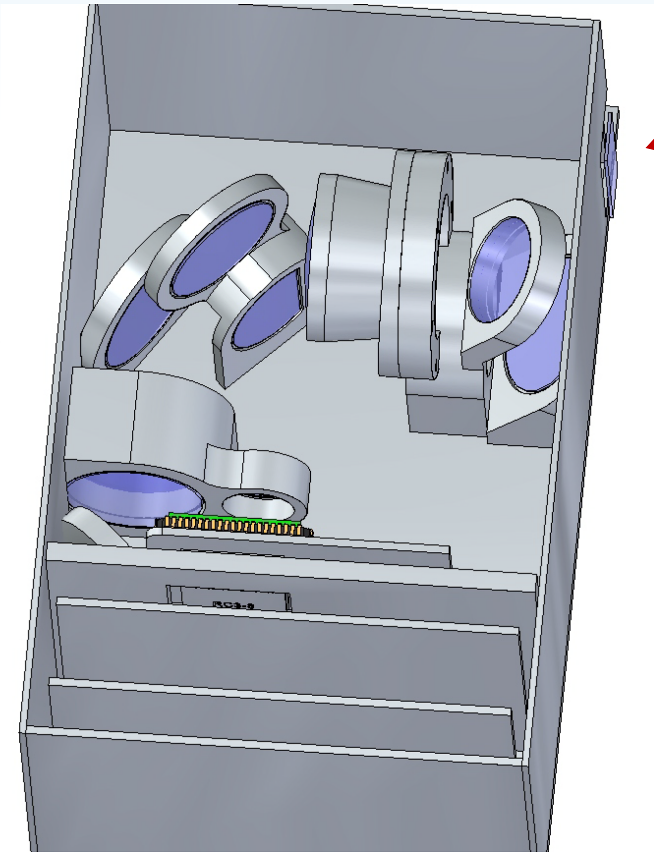
Dimensions indicate usage of pixels on the selected focal plane.

Each slit image covers 125 (spatial) by 64 (spectral) pixels.

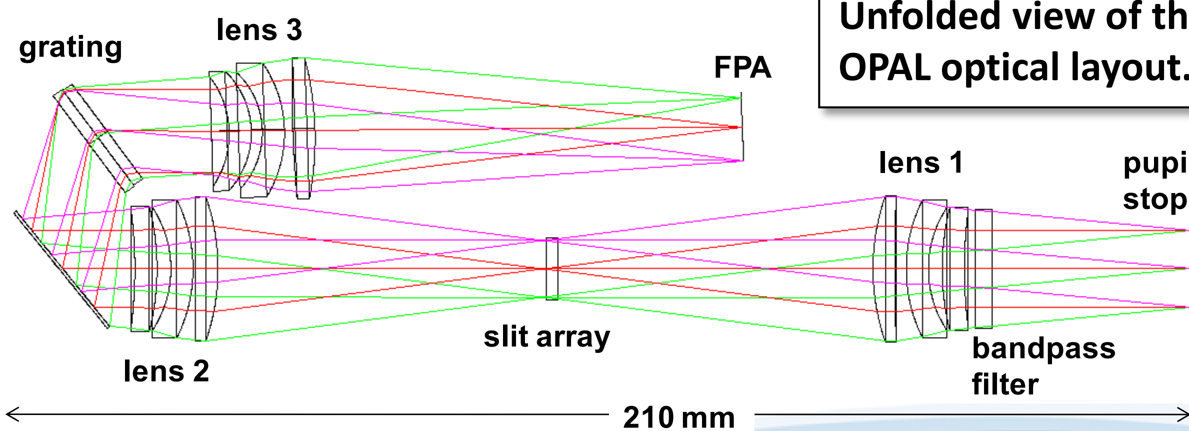
Most of the focal plane is unused.



Optical Design (final)



- Offner spectrometer replaced by a refractive collimator & re-imager.
- Lens 1 and Lens 2 are identical telecentric triplets.
- Dispersion is achieved by a planar transmissive grating (obtainium).
- 5 fixed fold mirrors; optical path folded over two levels.
- Baffles not shown.



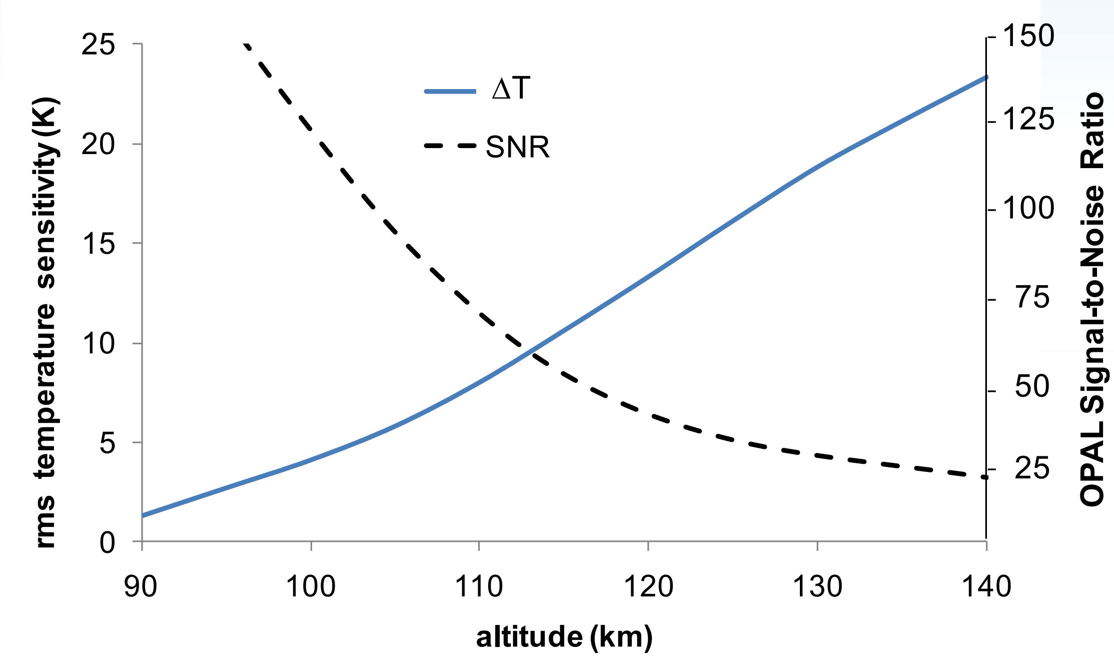
Unfolded view of the OPAL optical layout.

OPAL Performance

	requirements	predictions
spectral resolution	0.6 nm	0.5 nm (0.17 nm/pixel)
spectral band	759 – 769 nm	758 – 770 nm
vertical resolution	1.7 mrad	0.4 mrad
horizontal resolution	42 mrad	23 mrad
vertical FOV	14 mrad	33 mrad
horizontal FOV	166 mrad	188 mrad
sample period	18.5 s	17.2 s
SNR @ 100 km	50	124
SNR @ 140 km	12	19
data rate (average)	10 kbit/s	5.4 kbit/s

- SNR estimates include aggregation of redundant spectral and spatial samples.
- Extra FOV accommodates satellite pointing uncertainty.

OPAL Performance



optical parameters	values	system parameters	values	FPA parameters	values
focal length	55 mm	collection aperture	5 x 14 mm	pixel pitch	18 mm
spectral band	758 – 770 nm	slit width	54 μm	pixels utilized	125 x 578
FOV	2.3˚ x 10.8˚	pixel aggregation	3x3	detector efficiency	28%
foreoptics throughput	89%	FPA temperature	-15˚C	dark current	30 e-/s
spectrometer throughput	48%	stray light equiv.	11 kR/nm	readout noise	18 e-
BRDF per surface	0.002 sr^{-1}	exposure time	17 s	pixel capacity	82,000 e-
				max exposure	5,000 e-

Stray Light Predictions

stray light cause	**contributors**	**estimate** (kR/nm)
veiling glare	1st fold mirror bandpass filter lens group 1	7.0 0.6 1.3
contamination	1st fold mirror (class 300)	1.2
surface defects	all surfaces (class 20/15)	0.3
edge scattering	baffle scattering x slit diffraction	0.1
ghosting	fore optics spectrometer optics	0.2 0.1
out-of-band	slit cross-talk (10^{-3} rejection)	0.1
total – worst case	bright clouds below FOV	10.9

add contributions for worst-case stray light (not RSS)

OPAL Interfaces

mounting	forward nadir deck
envelope	70 x 98 x 178 mm, optics and electronics
temperatures	FPA at -15C; minimal heat loads to the spacecraft
radiator	ram-facing; 145 cm^2; flexible heat strap
power	2.4W peak, including all electronics, and thermal
electrical	SensorHub for power, data, C&DH, & heaters
mass	1.8 kg, including optics, structures, electronics, and radiator
data rate	5.4 kbit/s, daylight average commands & data flow through Iridium network onboard data aggregation
spacecraft ops	no maneuvers; Iridium-NEXT attitude ±0.08° with ±0.008° knowledge