LightSmyth Multi-Channel Spectrometer Based on Diffraction Grating Array

NASA SBIR Phase I

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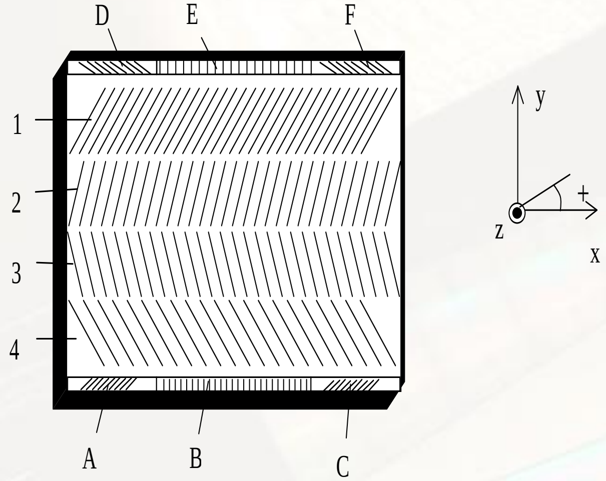
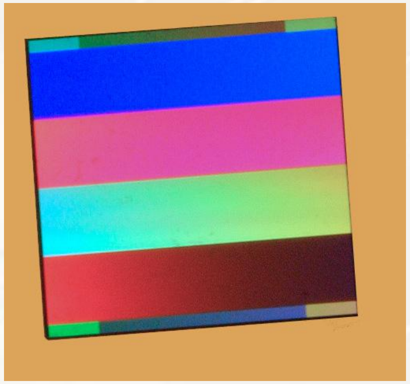
Outline

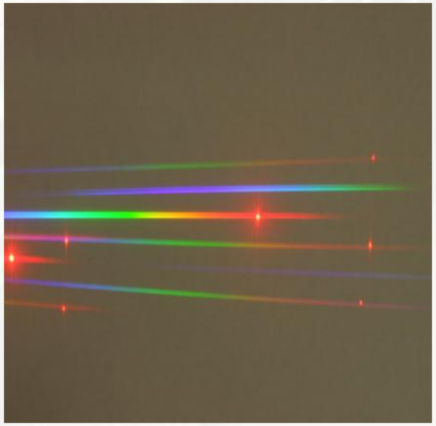
1. General Review of Technology
2. Project Objectives
3. Results
4. Conclusion

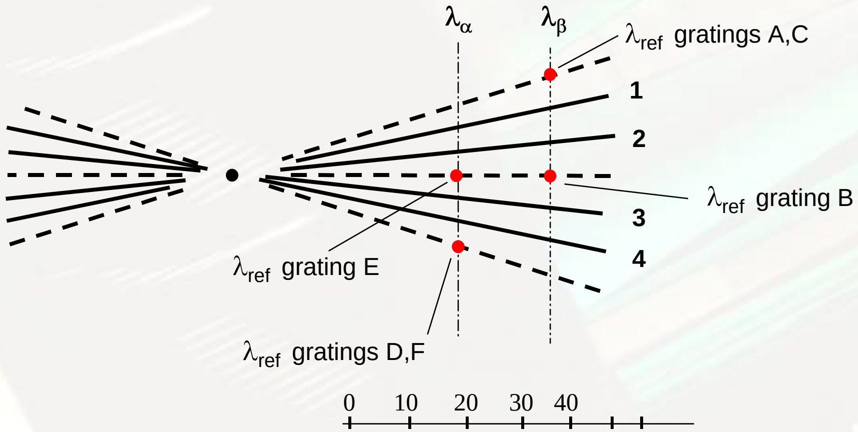
LightSmyth Multi-Channel Spectrometer Based on Diffraction Grating Array





Direction of grating grooves coherently combined on a flat silicon substrate





Intensity distribution in the output plane

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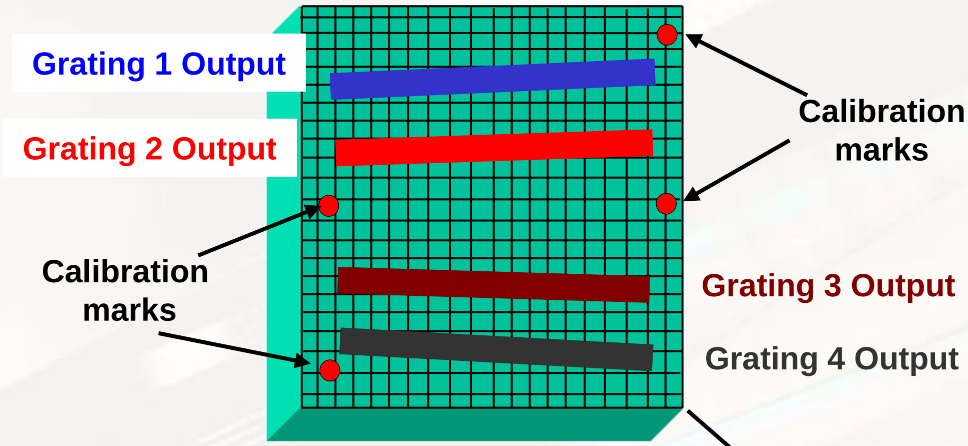
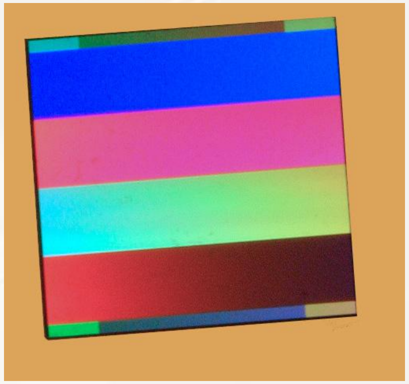
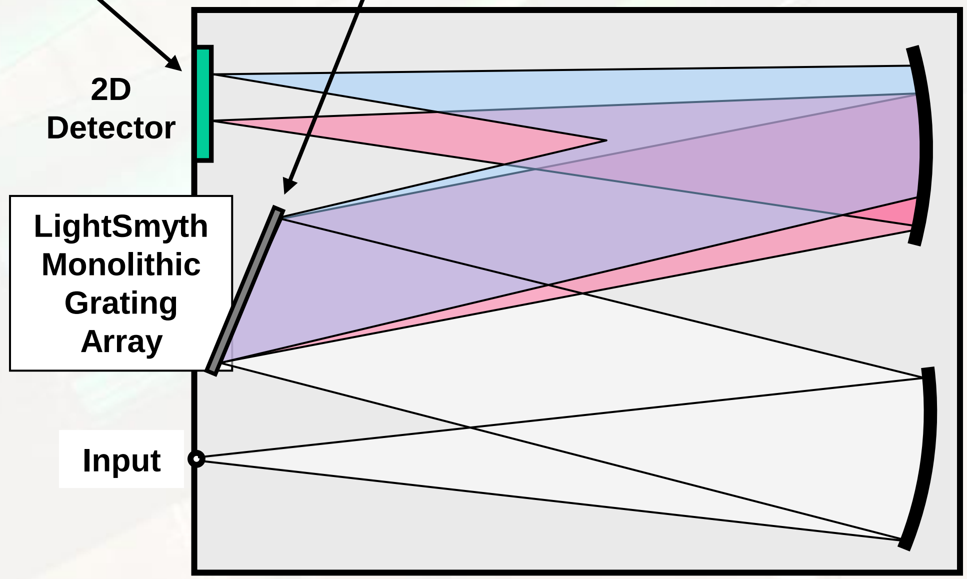






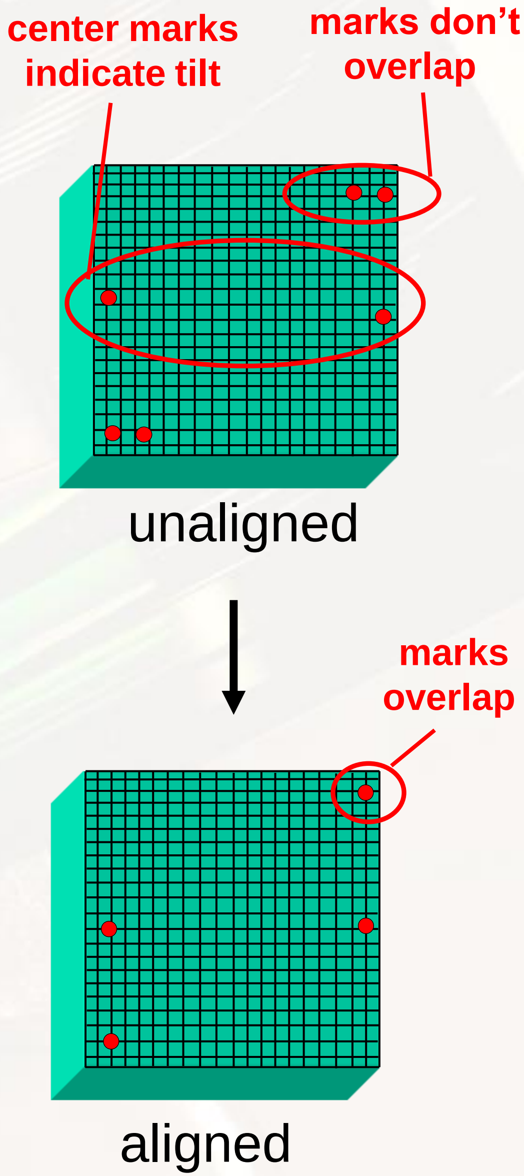
Diffraction Grating Array provides multiple dispersion planes for single input, uses advanced 2D sensor.

Internal wavelength calibration

Spatial alignment features

LightSmyth Multi-Channel Spectrometer Based on Diffraction Grating Array

- Spectral bands can be *continuous* or *discontinuous* (UV, visible and IR on the same grating substrate)
  - ⇒ Multi spectral channel capabilities
  - ⇒ Mitigates trade-off between high bandwidth and high spectral resolution
- Typical 1D sensor array has several Kpixels, while 2D sensor array has several Mpixels
  - ⇒ At least an order of magnitude better pixel resolution
  - ⇒ Can take into account distorted line shape to improve resolution/throughput.
- Single rugged monolithic dispersive element working in 2D
- Array-internal wavelength calibration and alignment markers
  - ⇒ Simplify assembly in manufacture
  - ⇒ Enable self-calibration after mechanical/temperature interference(remote environments)



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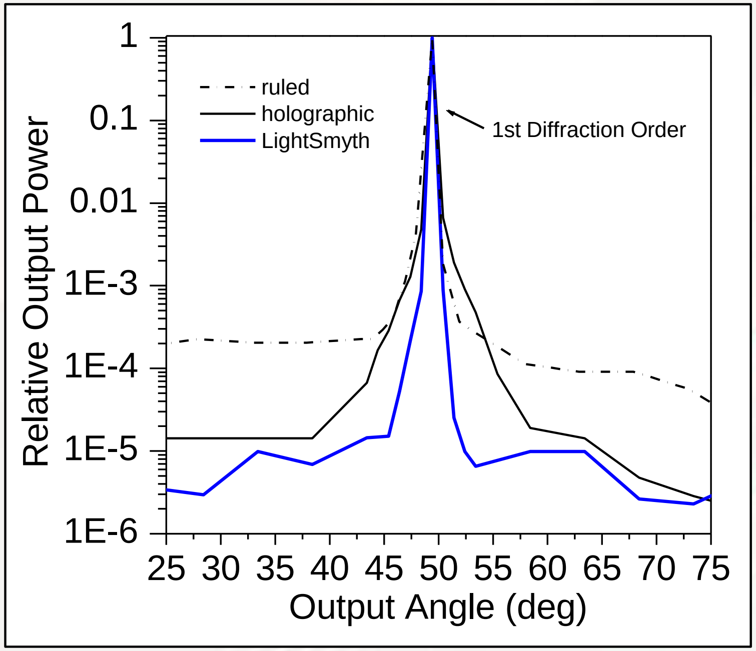

Note: The figure shows relative output power (normalized to first diffraction order peak) in the dispersion plane of a ruled (dotted), holographic (dashed) and LightSmyth (solid blue) 1200 lines/mm grating illuminated by a HeNe laser.

Light Scatter Analysis

The LightSmyth grating provides scattered light levels *up to two orders of magnitude lower* than the traditional gratings.

Spectrometer Type	Scattered Light Level
Holographic grating based spectrometers	10^{-3} to 10^{-4}
LightSmyth grating based spectrometers	10^{-5}
Double Monochromators	10^{-6}

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NASA SBIR Phase I Objectives:

1. Demonstrate ultra-compact spectrometer with broad spectral coverage and high resolution as a prototype of multi-channel remote trace gas sensor in Earth atmosphere deployable on ground, AEV, sub-orbital and orbital platforms.

2. Practical demonstration of DGA-based spectrometer may promote acceptance of the new diffraction element with OEM spectrometer companies.

Tasks:

- Optical design
- Mechanical design
- Software development
- Assembly
- Test

NO_{2}:	400 to 450 nm at 0.5 nm resolution.
CHOCHO, HCHO, BrO:	350 to 400 nm at 0.5 nm resolution
O_3 and SO_{2}:	300 to 330 at 0.5 nm resolution
H_2O:	505 to 515 at 0.5 nm resolution
H_2O:	905 to 915 at 1 nm resolution
Oxygen column:	around 760 nm

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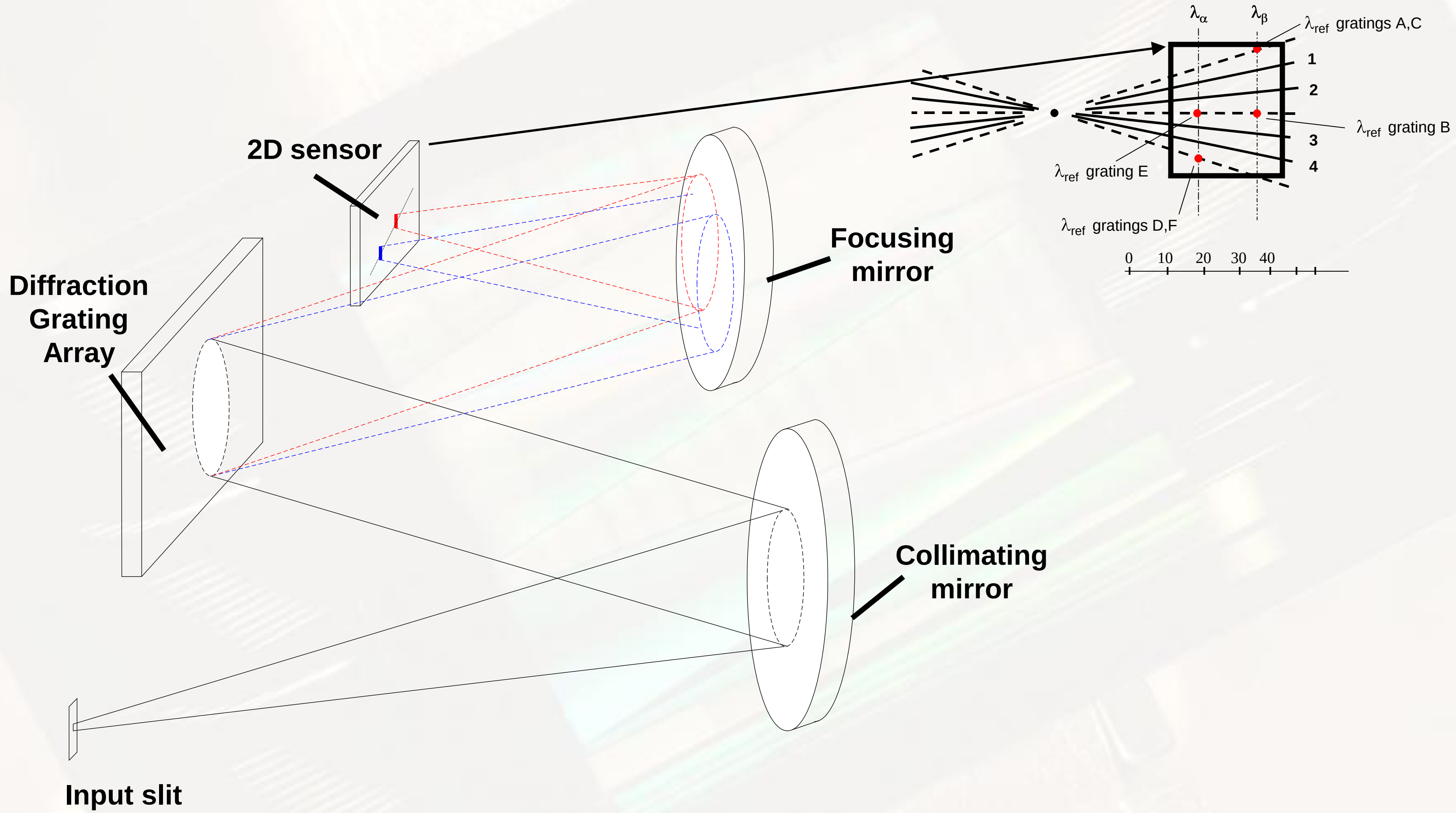

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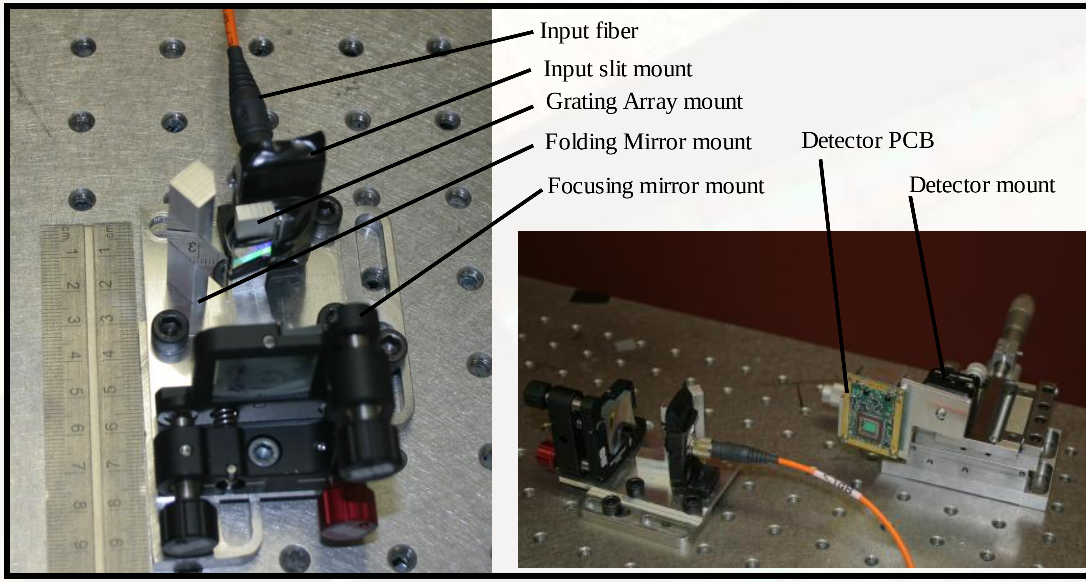

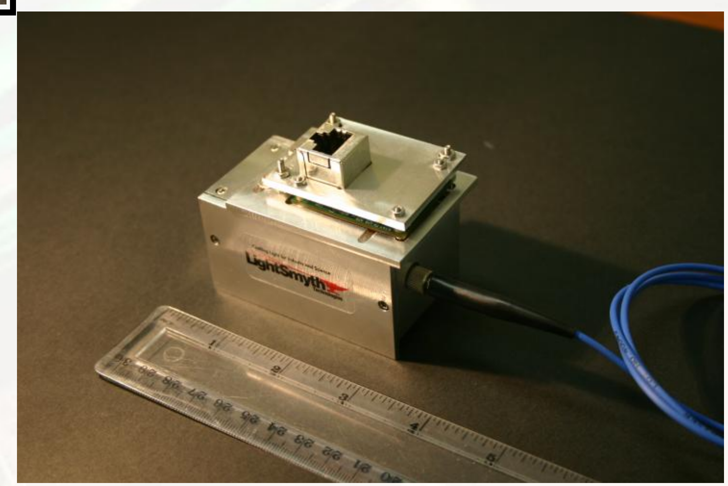

Ebert –Fastie Spectrometer (Single reflective mirror acting as both collimating and focusing mirrors)

Top Left-Center: original breadboard prototype

Top Right: final prototype w/o detector module

Top Bottom: final prototype with detector module

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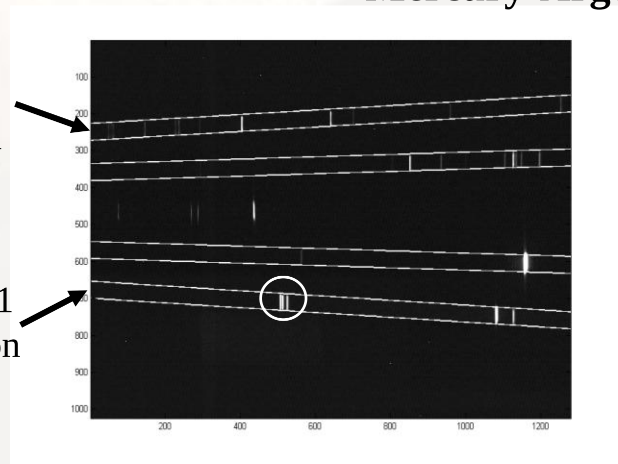
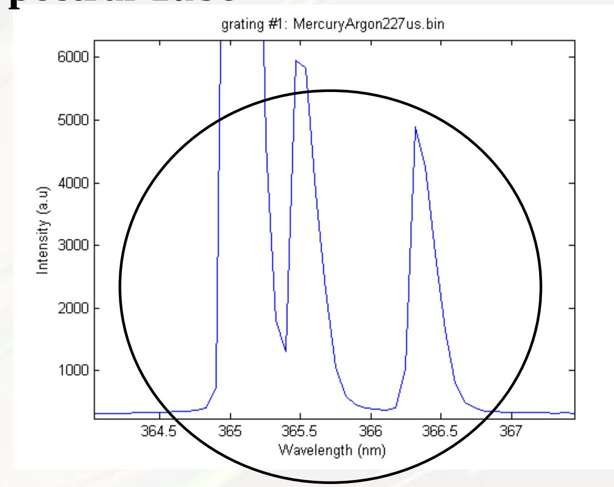
Mercury-Argon Spectral Tube

Grating 4 dispersion

Grating 1 dispersion



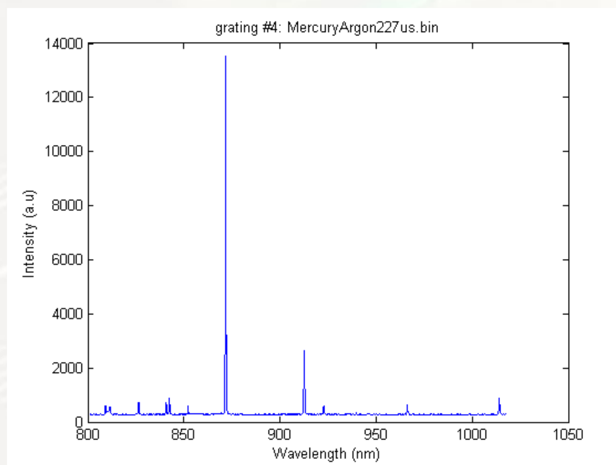


Top Left: Intensity distribution on detector plane

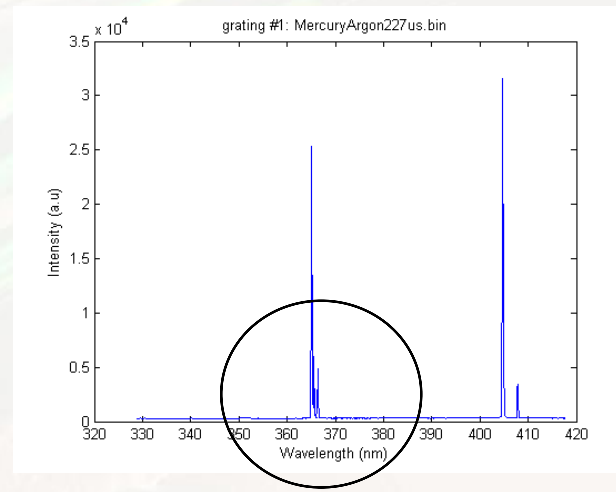
Bottom Left: Intensity vs wavelength, gr.#4

Bottom Right: Intensity vs wavelength, gr.#1

Top Right: Intensity vs wavelength, gr.#1 (zoom in), separation between two lines is less than 0.5 nm



Grating 4



Grating 1

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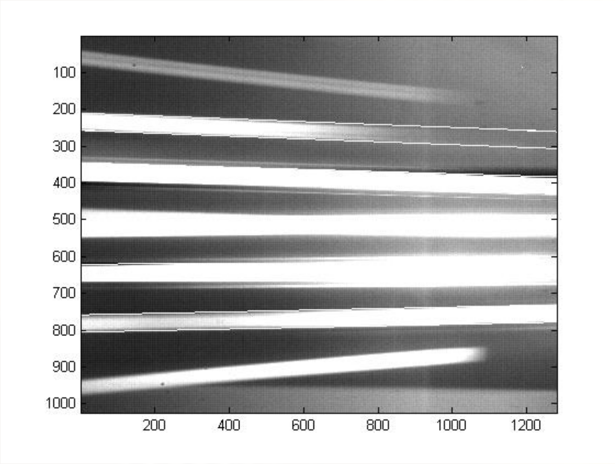
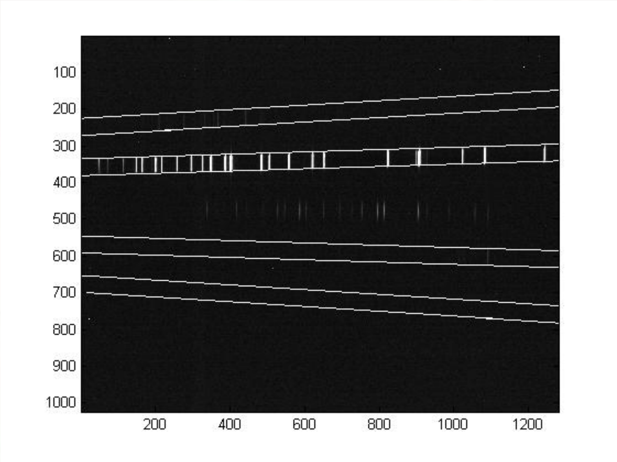
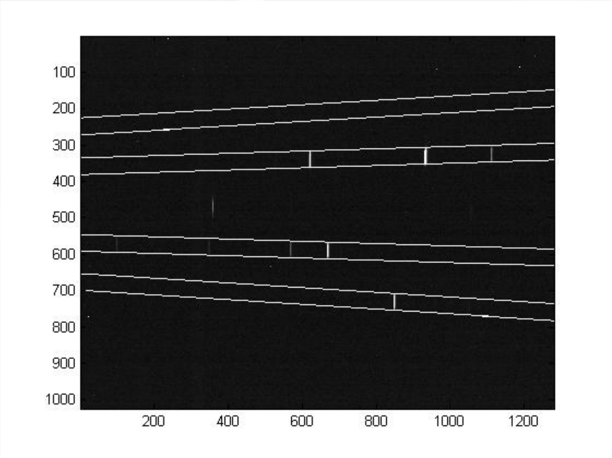
Intensity distribution on the detector



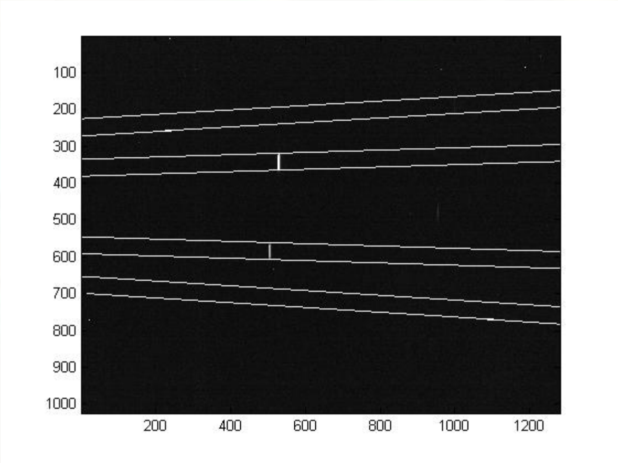
Broadband source



Neon



Helium



Hydrogen

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Parameter	*LightSmyth prototype*	*HR4000CG (Ocean Optics)*
Resolution	0.16 (UV) to 0.45 (IR)	0.75
Operation Range	330 nm to 1100 nm	200 to 1100 nm
Input Slit:	5 µm	5 µm
Design:	Ebert –Fastie, f/4	Czerny-Turner, f/4
Focal Length:	35 mm	101.6 mm
Size	75 x 50 x 45 mm.	148.6 x 104.8 x 45.1
Weight	240 grams	570 grams
Input	Fiber, NA 0.22, core 200 µm	Fiber, NA 0.22, core 400 µm

Already at first iteration achieved 2x reduction in mass, 4x reduction in volume, 2x improvement in resolution compared to one of the leading spectrometers in the class.

Still a lot of room for optimization, both optically and mechanically

HR4000CG (Ocean Optics)

LightSmyth prototype

Conclusion

- Demonstrated a spectrometer prototype based on new type of optical element - **diffraction grating array** - with superior optical performance and mechanical footprint
- Can lead to new class of monolithic multi-channel spectrometers with small number of optical elements “zoomed” into non-contiguous wavelength regions of interest with high spectral resolution
- Small size and weight coupled with high optical performance makes it ideal for sub-orbital and orbital remote sensing missions.

Next step:

- Phase II – ground based spectrometer that may replace $2 million FT instrument for trace gas species in Earth atmosphere and imaging spectrometer for UAV
- Working with UAH – proposal to develop satellite with imaging spectrometer for remote atmospheric sensing

Special thanks to NASA SBIR program for making this happen and Dr. Jessica Gaskin (MSFC) for application input.