Project Report
LSP-251

CRISP Flight Campaign: FY18 Optical Systems Technology Line-Supported Program

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A.B. Milstein

17 January 2019

Lincoln Laboratory
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LEXINGTON, MASSACHUSETTS

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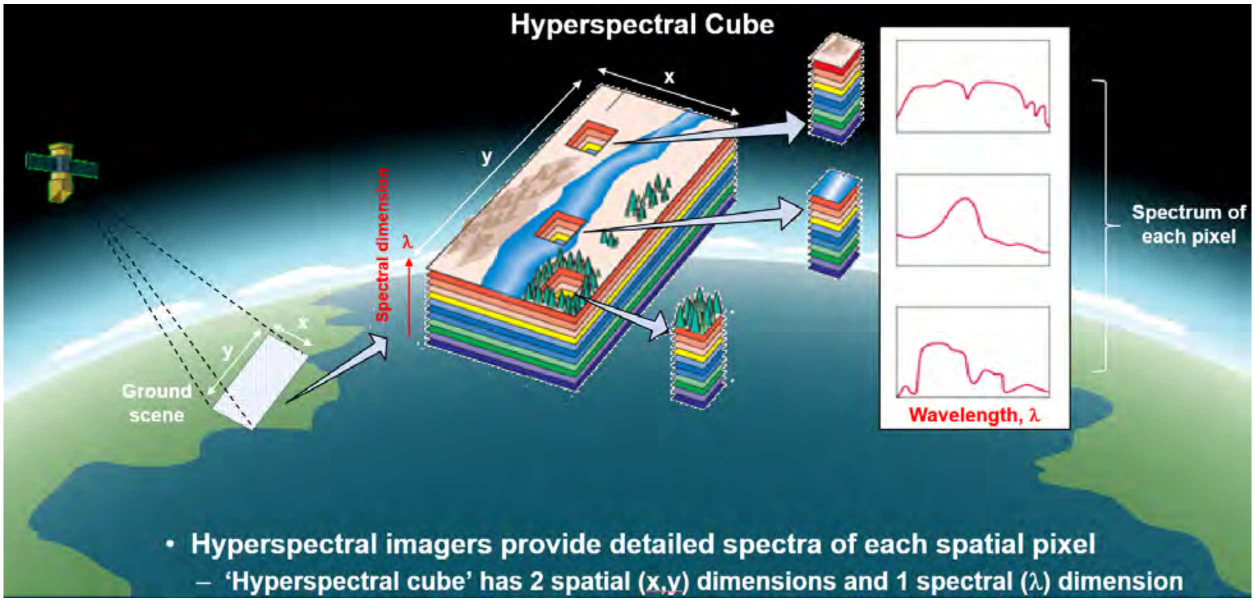
EXECUTIVE SUMMARY

The CRISP multiplexing architecture enables high performance and low SWaP hyperspectral imaging systems. A flight ruggedized CRISP spectrometer was designed and built for a flight demonstration on Lincoln Laboratory's Cessna aircraft. Flight tests to collect emissivity spectra of sand and ocean water over the Plum Island and Cape Cod regions have demonstrated that the CRISP concept is robust under real-world conditions.

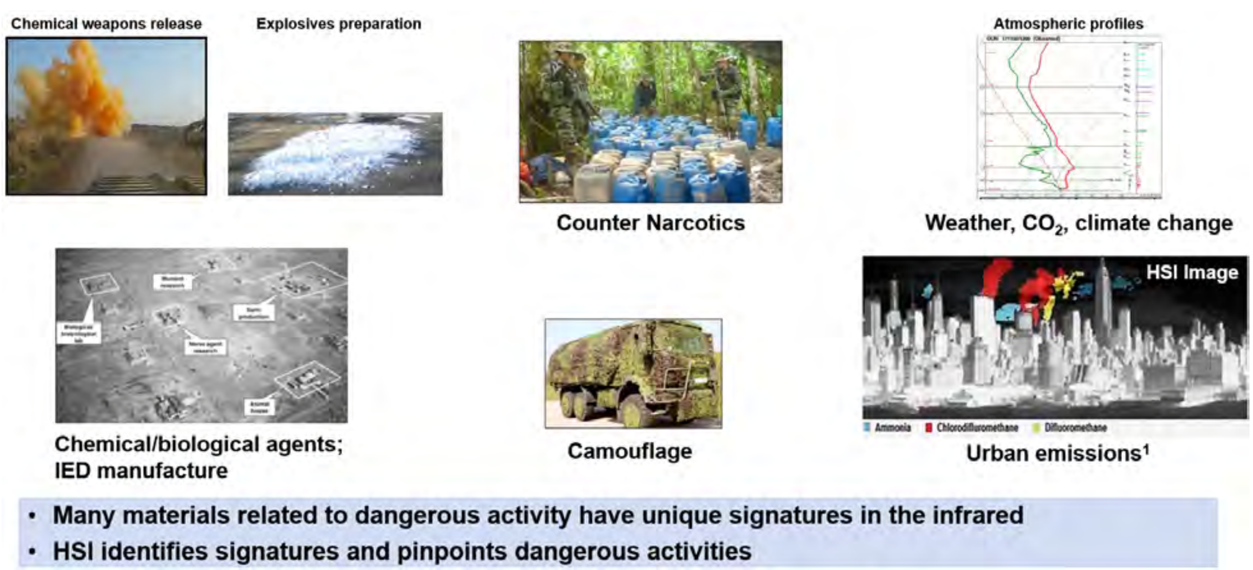
TABLE OF CONTENTS

1. INTRODUCTION

1.1 WHAT IS HYPERSPECTRAL IMAGING (HSI)?



1.2 WHY HYPERSPECTRAL IMAGING?



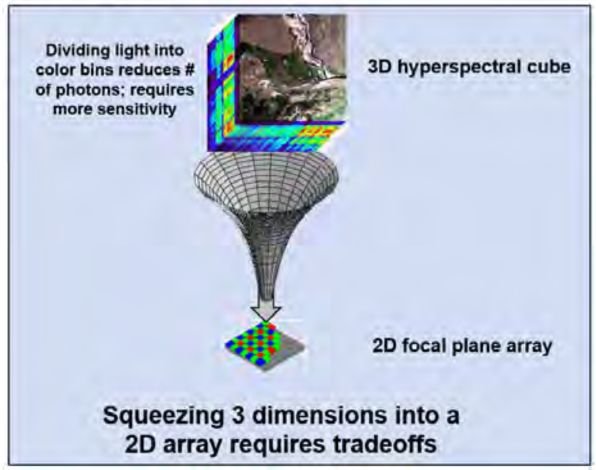
1.3 IMAGING SPECTROMETER CHALLENGES

- **Challenge: Imaging spectrometers expensive, hard to miniaturize**
  - **Typically (infrared) require cryogenically cooled focal planes to achieve required performance**
    - **Liquid nitrogen-cooled HgCdTe arrays**
    - **Expensive to launch; limited lifetime**

Space Weather Sensor Examples

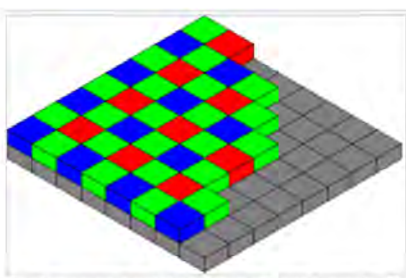
Atmospheric Infrared Sounder (AIRS)	Cross-track Infrared Sounder (CrIS)
	

  - **Goal: Global, persistent coverage**
    - **E.g., Small satellite constellation**



1.4 CONVENTIONAL 3-COLOR RGB IMAGING

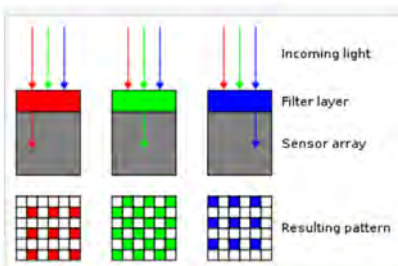
Bayer color filter (absorptive)



The Bayer arrangement of color filters on the pixel array of an image sensor

Common architecture for many consumer cameras (e.g. phones, …)

Absorptive filters on each pixel



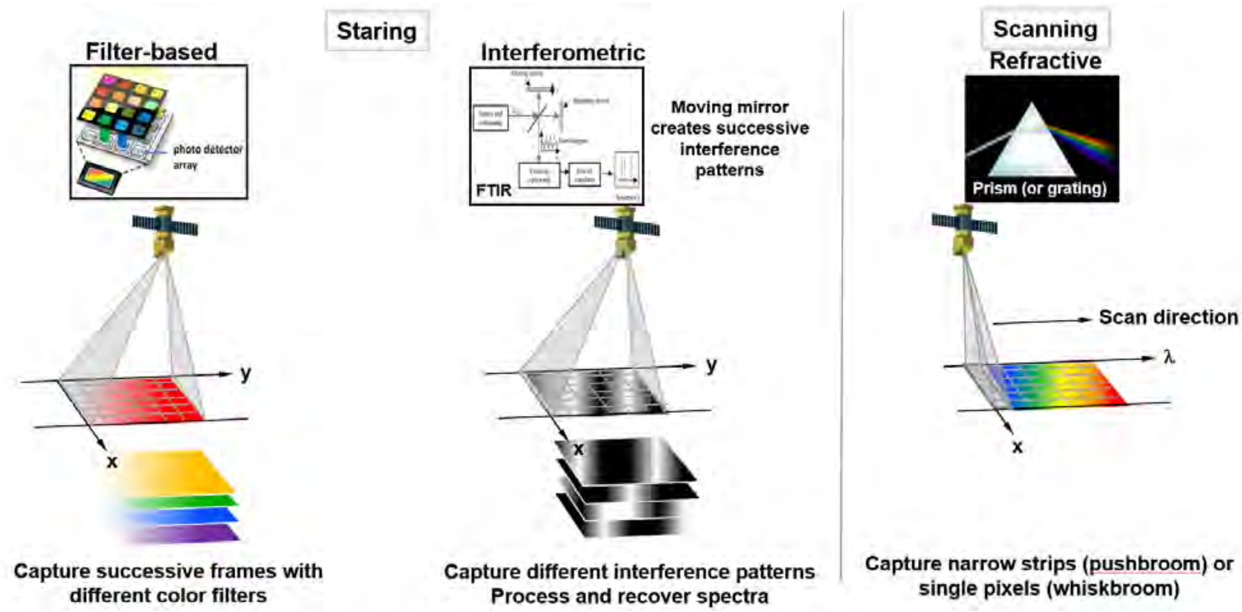
- 3 colors (RGB)

- Each pixel receives only 1 color (decreased overall throughput)

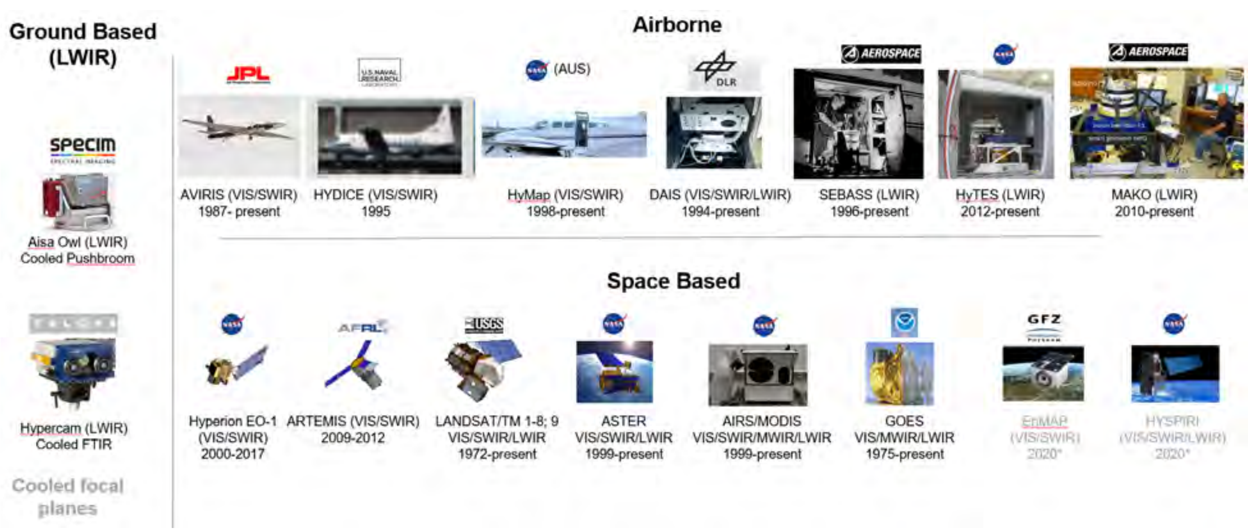
- Interpolate other colors using neighbor pixels (spectral blurring)

Commercial cameras sacrifice color resolution and sensitivity for FPA simplicity

1.5 PASSIVE IMAGING SPECTROMETERS

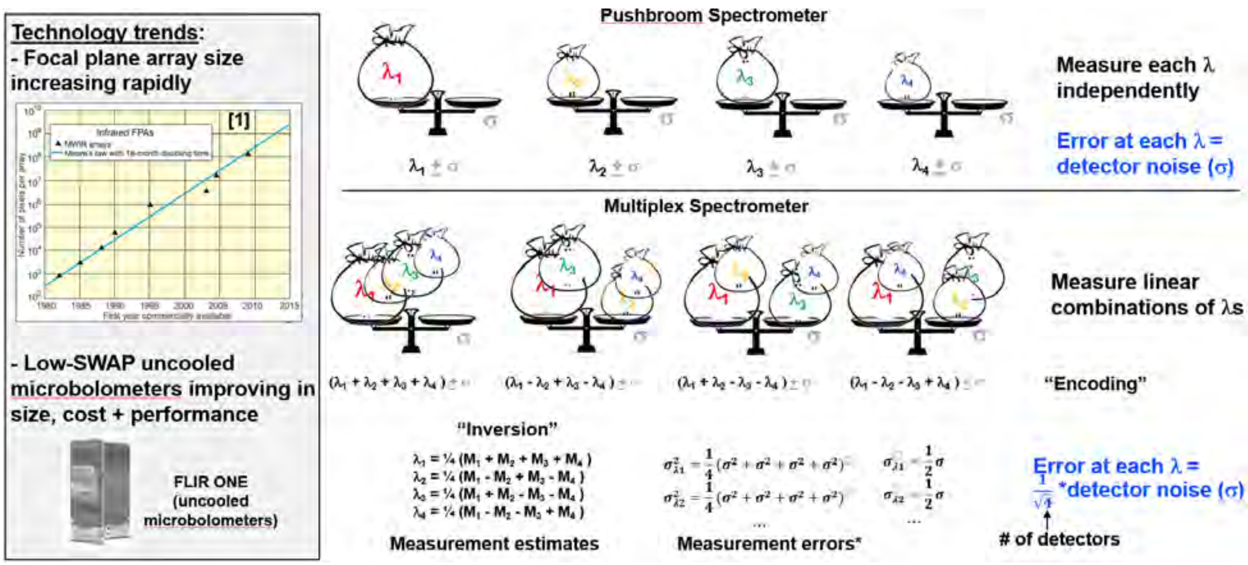


1.6 SPECTRAL IMAGING SYSTEMS

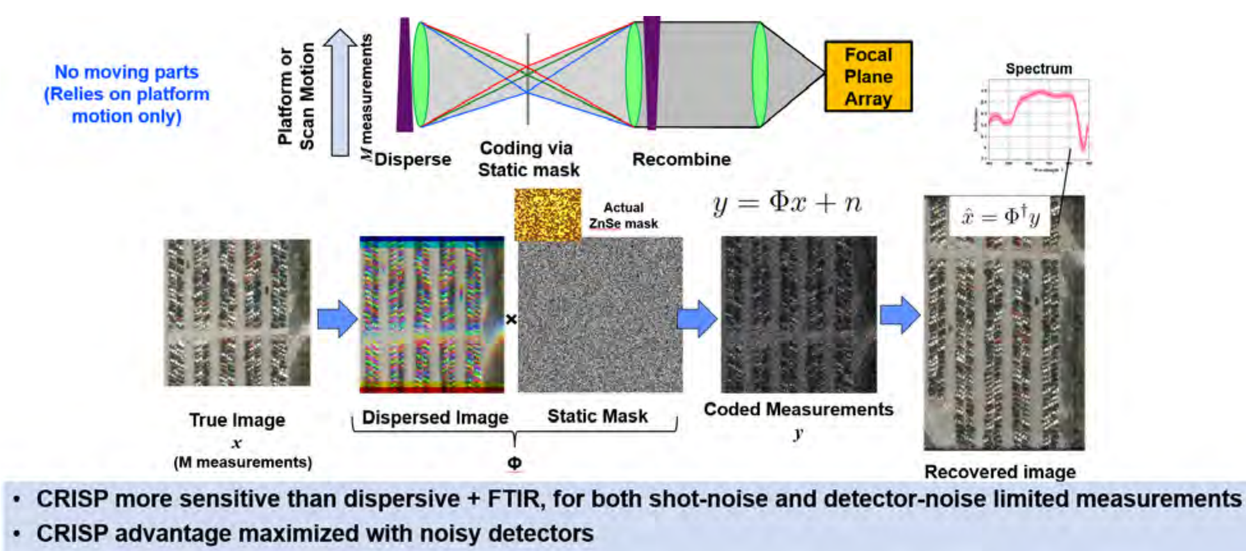


2. MULTIPLEXING, COMPUTATIONAL IMAGING, AND CRISP… DOING MORE WITH LESS

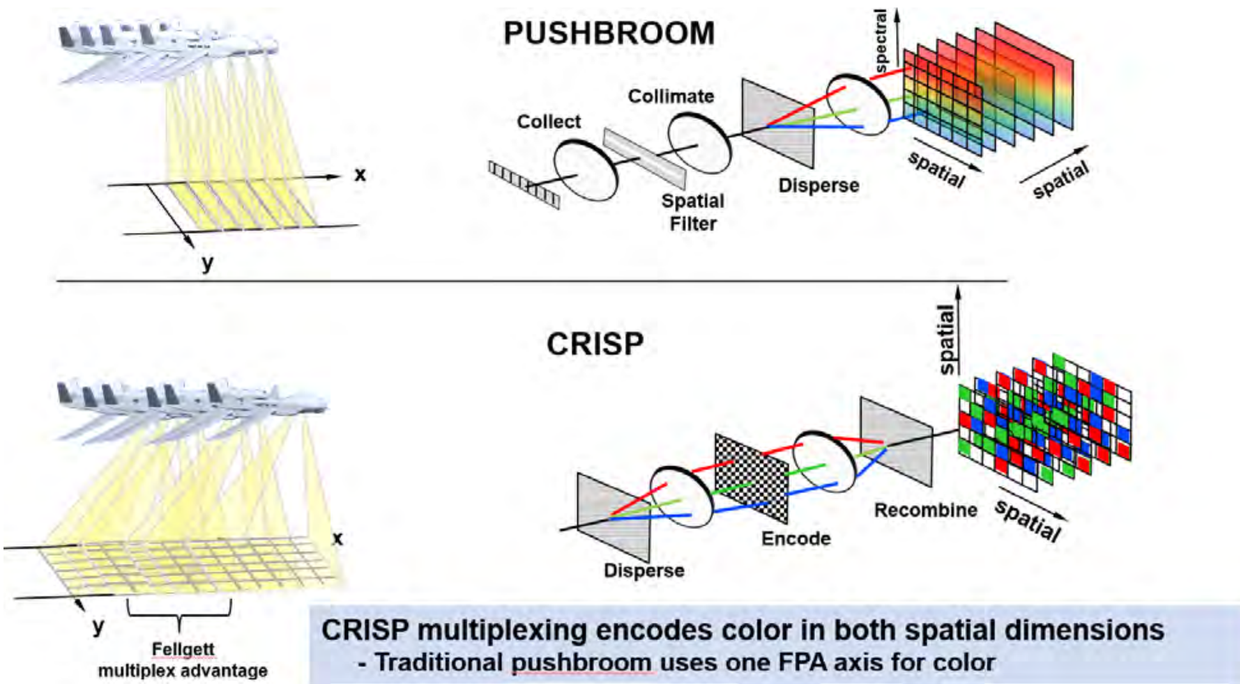
2.1 MICROBOLOMETERS AND MULTIPLEXING



2.2 CRISP SPECTRAL DECODING

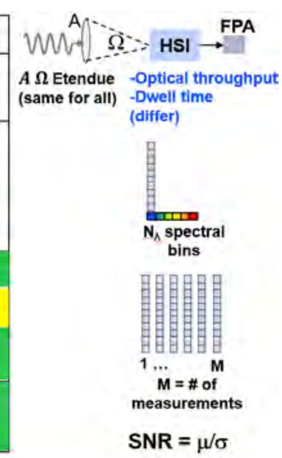


2.3 HYPERSPECTRAL IMAGER OPERATION



2.4 COMPARISON OF HSI SYSTEMS

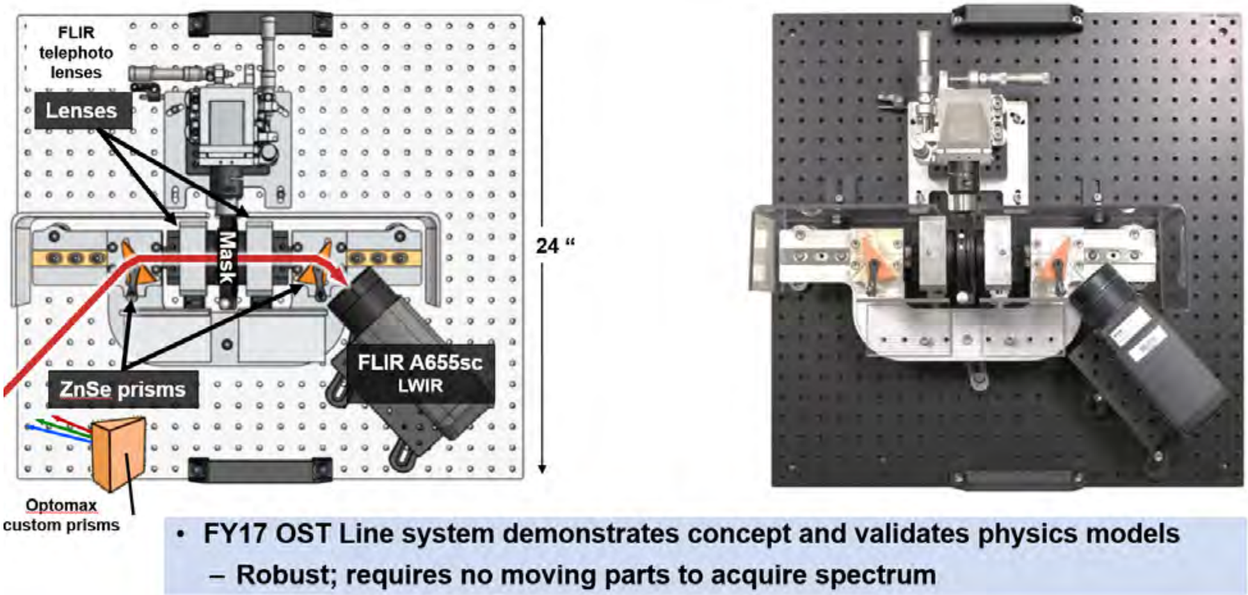
	Pushbroom	FTIR	CRISP
Spectral formation for single pixel	GSD Δt t	$M = 2 N_\lambda$ FFT	$M \geq N_\lambda$ $x = \phi^{-1} y$
Dwell time	Δt	M Δt	M Δt
Throughput	1	½ (beamsplitter)	½ (mask)
Photon-limited SNR	$\frac{SNR_{Pushbroom}}{SNR_{Pushbroom}} = 1$	$\frac{SNR_{FTIR}}{SNR_{Pushbroom}} = \frac{1}{2}$ [1]	$\frac{SNR_{CRISP}}{SNR_{Pushbroom}} = \sqrt{\frac{M}{2N_\lambda}}$ [2]
Detector-limited SNR	$\frac{SNR_{Pushbroom}}{SNR_{Pushbroom}} = 1$	$\frac{SNR_{FTIR}}{SNR_{Pushbroom}} = \frac{1}{4}\sqrt{\frac{M}{2}}$ [1]	$\frac{SNR_{CRISP}}{SNR_{Pushbroom}} = \frac{\sqrt{M}}{2}$ [2]



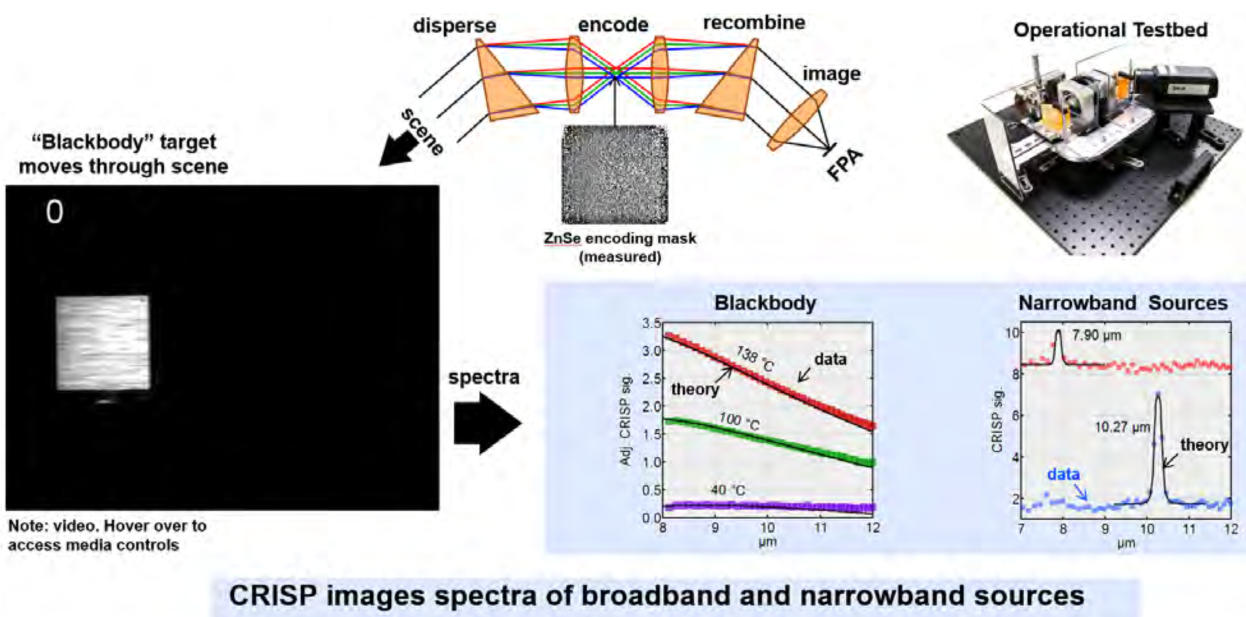
CRISP multiplex advantage improves performance in both photon-limited and detector-limited situations
- Improves with number of measurements M (FPA size)

3. CRISP PROOF-OF-CONCEPT

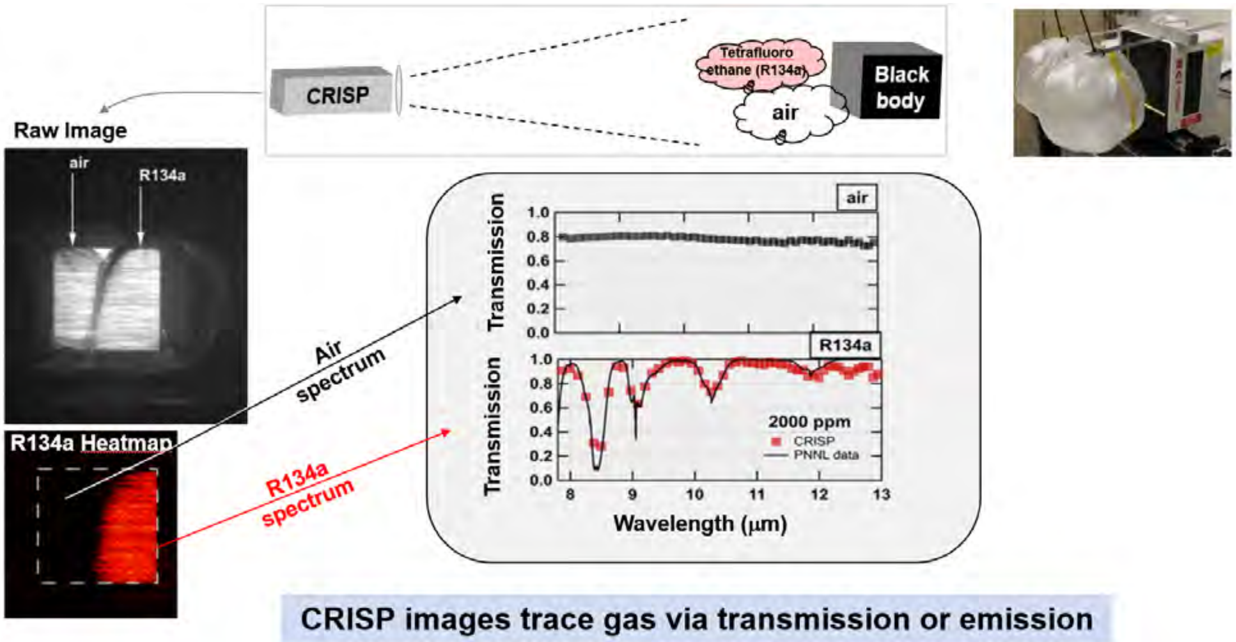
3.1 CRISP PROOF-OF-CONCEPT TESTBED



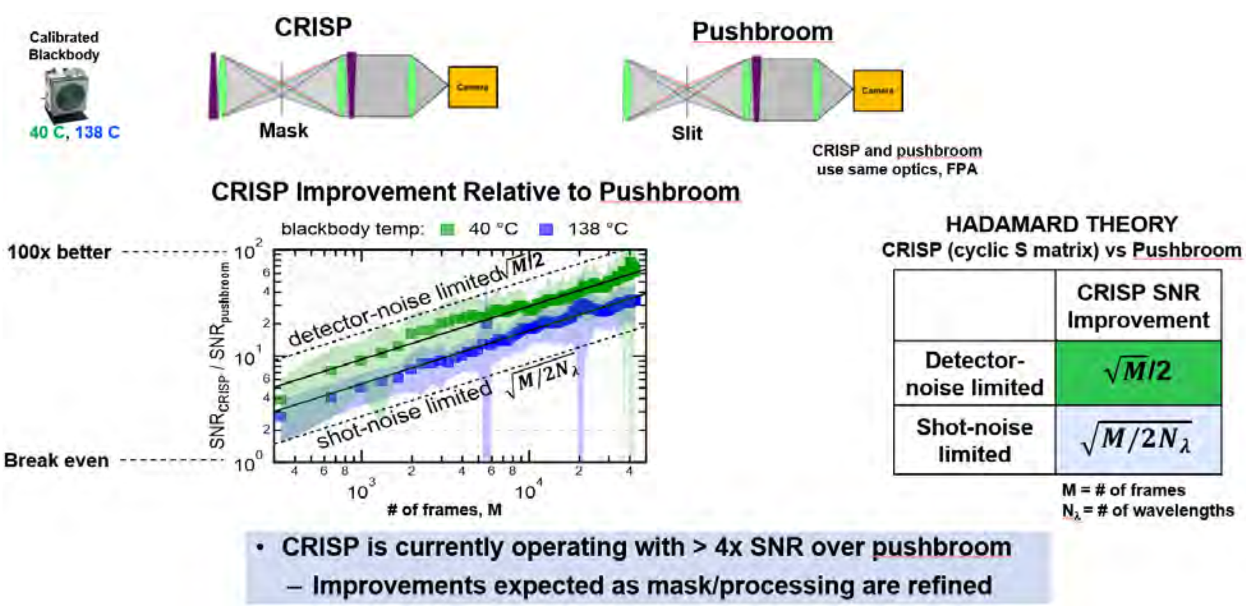
3.2 CRISP HYPERSPECTRAL IMAGERY



3.3 CRISP APPLICATION: TRACE PLUME DETECTION

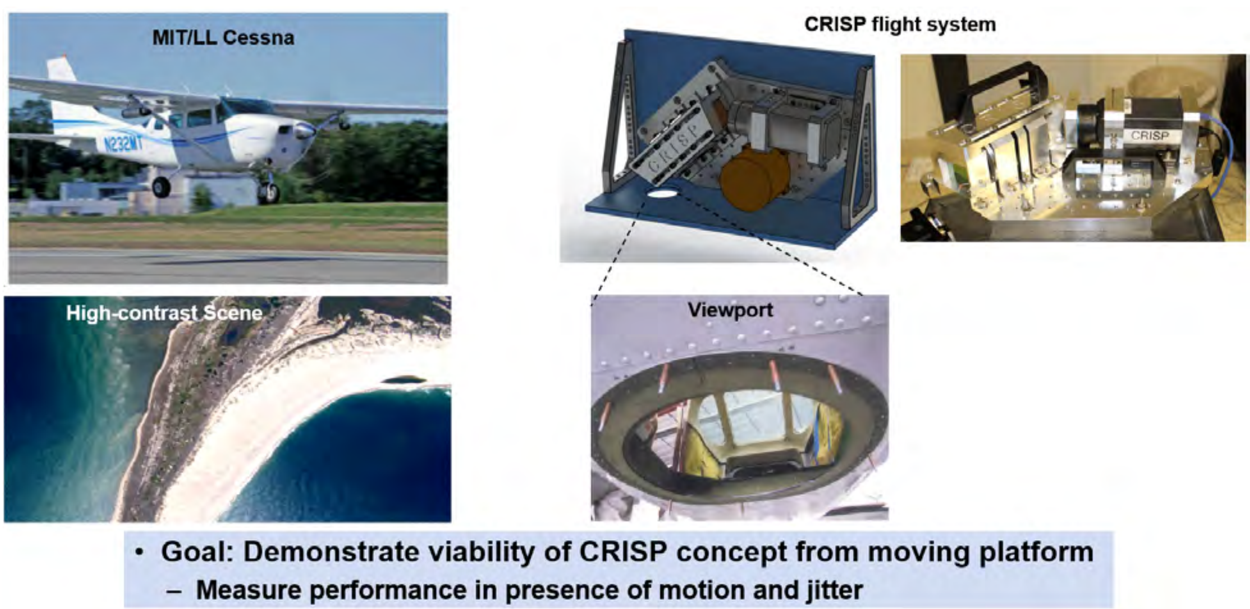


3.4 CRISP SENSITIVITY ADVANTAGE

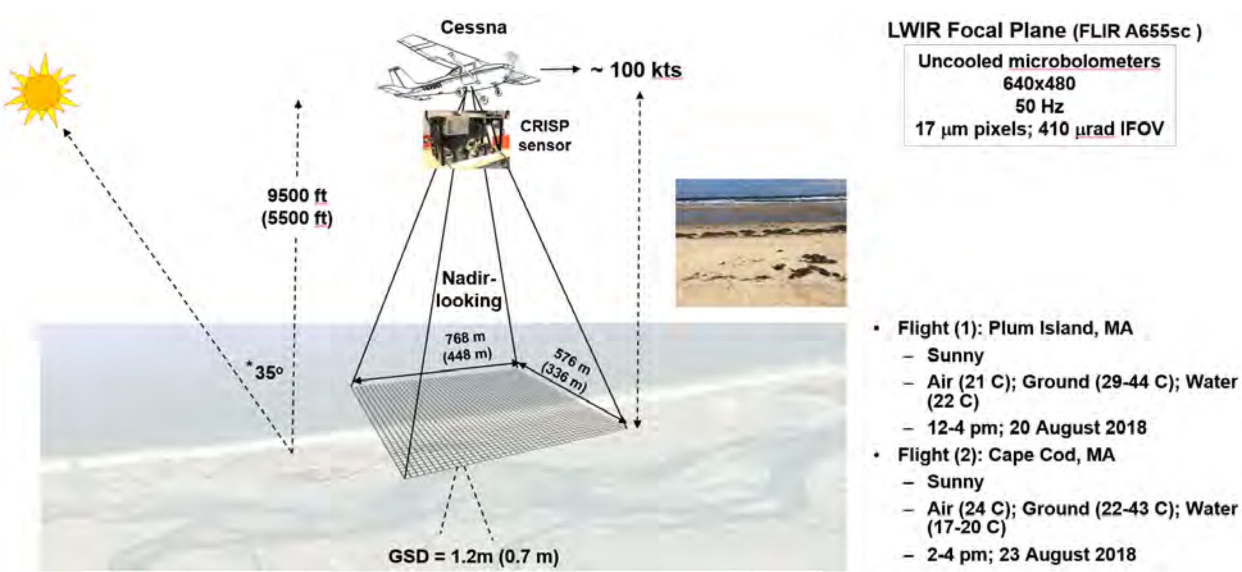


4. CRISP FLIGHT TESTS

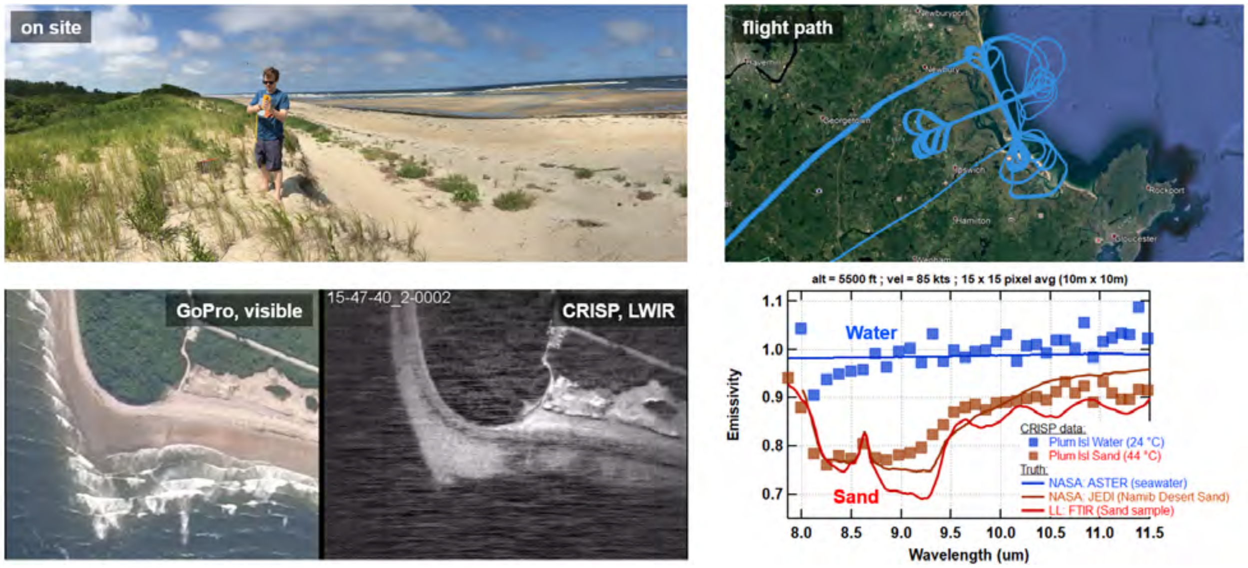
4.1 CRISP FLIGHT TEST PROGRAM FY18 OST LINE



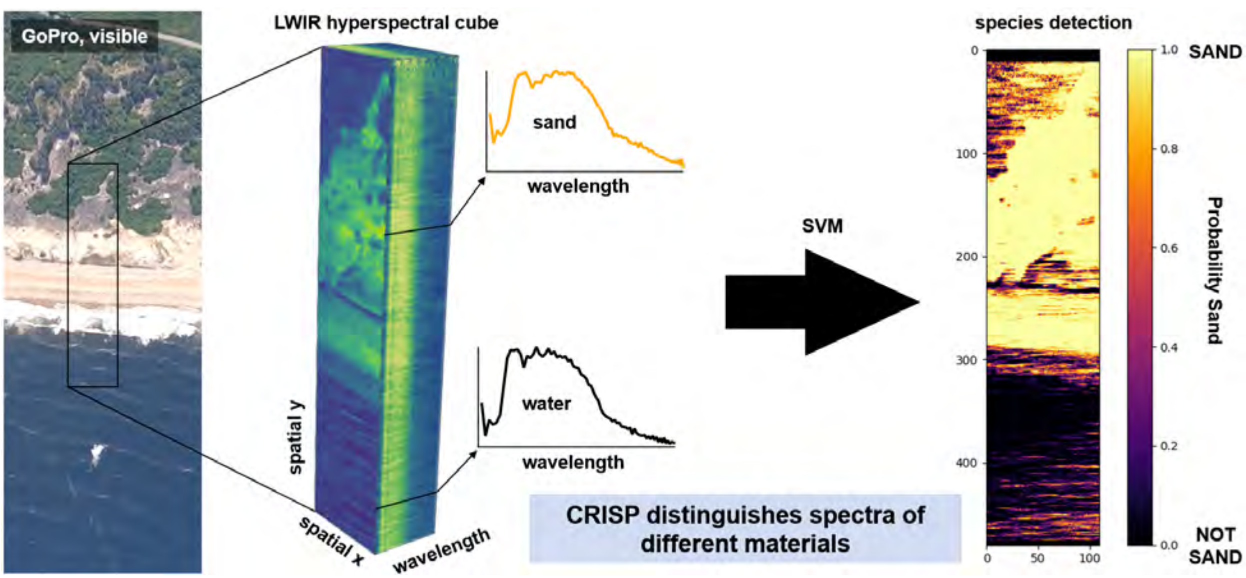
4.2 CRISP FLIGHT COLLECTIONS



4.3 CRISP SPECTRA: PLUM ISLAND COASTLINE



4.4 CRISP HYPERSPECTRAL IMAGERY



5. ACKNOWLEDGEMENTS

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  - **Ryan Sullenberger, John Lessard, Yaron Rachlin, Zach Palmer, Sumanth Kaushik (Gp 91)**
  - **Adam Milstein (Gp 97)**
  - **Corrie Smeaton, Phil Chapnik (Gp 78)**
- **Funding**
  - **OST Line support**
  - **NASA (ACT)**

- **Publications**
  - **"Computational reconfigurable imaging spectrometer", R. M. Sullenberger, A. B. Milstein, Y. Rachlin, S. Kaushik, and C. M. Wynn, *Opt. Expr.* 25, 31960 (2017).**
  - **Invention disclosure: "Computational reconfigurable imaging spectrometer (CRISP)", A. Milstein, Y. Rachlin, C. Wynn, R. Sullenberger, S. Kaushik; Filed 2017.**

REFERENCES

Sullenberger, Ryan M, Adam B Milstein, Yaron Rachlin, and Kaushik Sumanth, "Computational reconfigurable imaging spectrometer," *Opt. Expr.* 25 (31960), 2017.