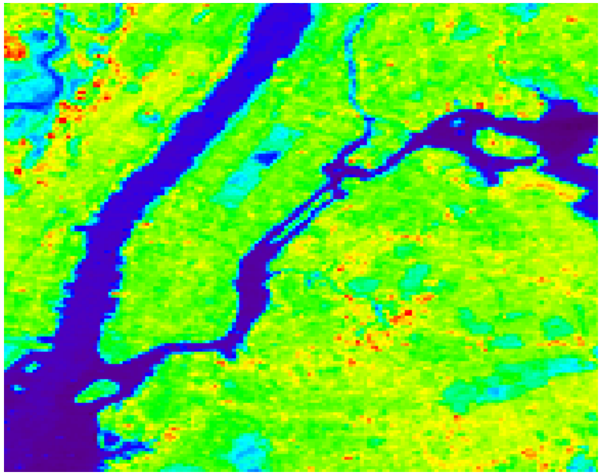
Trade-Off Study for High Spectral, High Resolution Thermal Infrared Mission for Surface Applications



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Background and Motivation

- Numerous scientific Earth observation applications require thermal infrared (TIR) imagery at high spatial (100m) and spectral (50nm) resolution over the range 3-14μm [1]
- Majority of operational TIR satellite sensors provide data at multiple spectral bands at spatial resolutions of 1km (e.g. SLSTR, VIIRS) or 100m resolution but limited spectral bands (e.g. Landsat TIRS and future ESA LSTM)
- We have performed a study, funded by CEOI, to explore the possibility of developing a TIR instrument with high spatial resolution and hyperspectral capability to meet the science goals, explore the limitations, and propose potential solutions

[1] HIRTII Study Scientific Requirements table, University of Leicester

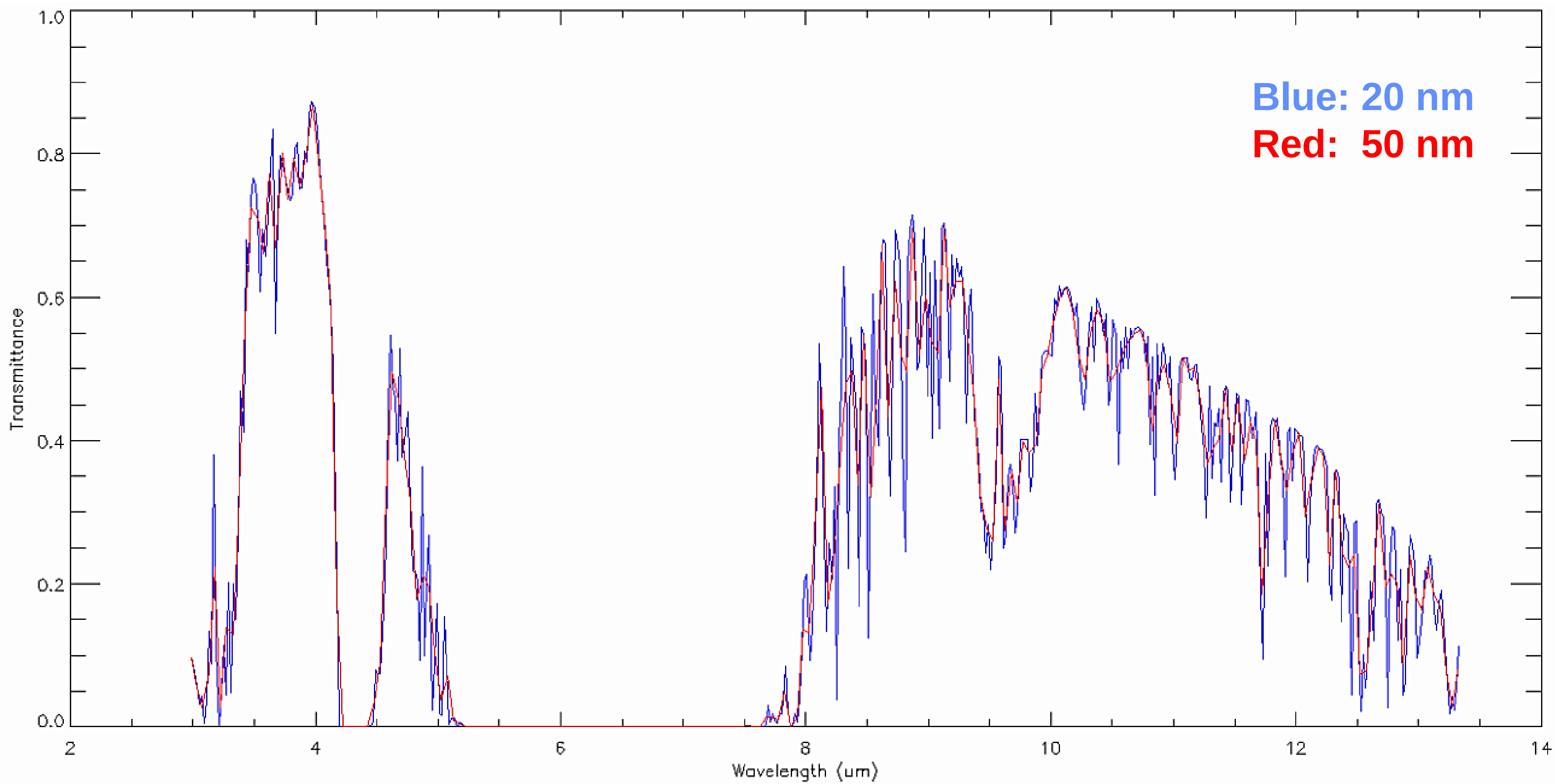
Potential applications

Domain	Application
Volcanoes and Earthquakes	Detection of Earthquakes and Pre-eruptive volcanoes
	Hot spots and active lava flows
	Post eruptive studies on lava flows
	Eruption clouds and Tropospheric plumes
Fires	Detection of fires, potential coal fires, coal mine fires
	Estimation of burnt area, fire intensity and severity
Hydrology	Detection of water stress in crops and forests
	Detection of evapotranspiration in crops, river basins, and continents
	Prediction and monitoring of floods
	Mapping irrigated land
	Cooling Degree Day estimations
	Growing Degree Day estimations and mapping

Domain	Application
Urbanisation	UHI: Surface temperature maps, Vegetation maps, Land cover/Land Use, Building Information, Air Quality
	Security and surveillance
	Industrial/power plant monitoring
	Air pollution
	Differentiate between urban and industrial zone
	Detection of Oil spill and Plume
	Mapping malaria and/or cholera potential regions
	Arthropod vector ecology and disease distribution
	Mapping meningitis outbreak
	Asbestos-cement detection (non-accessible areas)
	Detection of minefields
	Trafficability (off-road soil moisture content)
Surface Variability	Soil composition
	Identifying geothermal resources
	Mapping geothermal anomalies
	Mapping dynamic variability of surface temperature and emissivity

Spectral range and resolution

Gases: N_2, O_2, CO_2, O_3, H_2O, CH_4, N_2O, CO, HOCl, HCN, COF_2, H_2O_2, C_2H_2, C_2H_6, OCS



50nm: lowest spectral resolution to determine absorption features and retrieve surface properties

Instrument Design Drivers

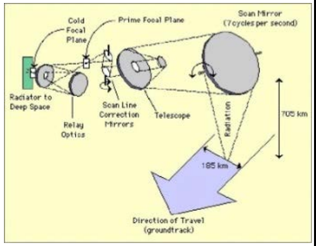
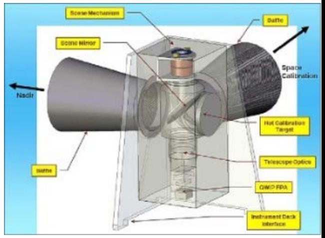
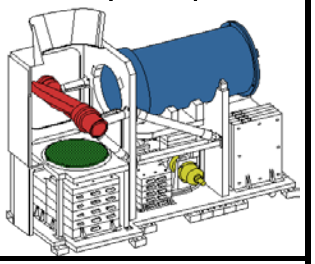
Science drivers requirements

- Spectral resolution: ~50nm
- Spatial resolution: ~100m
- NEdT: ~200mK
- Repeat times: hourly-daily

Considerations: instrument design trade-offs

- Detector performance
- Optics: telescope and spectrometer size
- Spectral selection
- Calibration

Operational High Resolution TIR Imagers

Satellite Instrument	Landsat 7 ETM+	Landsat 8 TIRS	ASTER (Terra)
			
Spectral band (µm)	10.4 -12.5	10.6-11.2 11.5-12.5	8.1-8.5 8.5-8.8 8.9-9.3 10.3-10.9 10.9-11.7
Resolution	60m	100m	90m
Swath width	185km	185km	60km
Detector, NEDT	HgCdTe (8), 0.20K @ 300K, 0.20K @ 320K	QWIP (3), 0.4K @ 300K 0.35K @ 320K (0.3K @ 360K)	HgCdTe (10x5), 0.3K @ 300K

Key points:

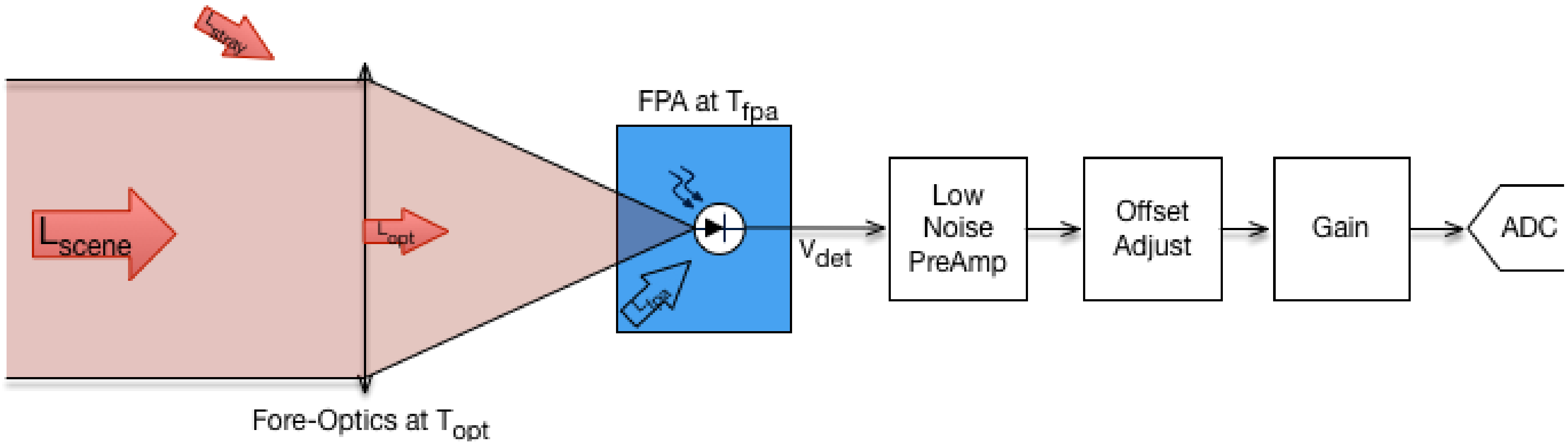
- Filter radiometers with limited spectral bands
- Limited repeat times due to narrow swath

ECOSTRESS

- HYSPIRI prototype (on ISS 340km)
- TIR spectral bands (µm): 8.3, 8.8, 9.1, 10.5, 12.1,
- Resolution: 60m
- Swath width: 360km
- NEdT: 0.5K
- Repeat time: 5-day

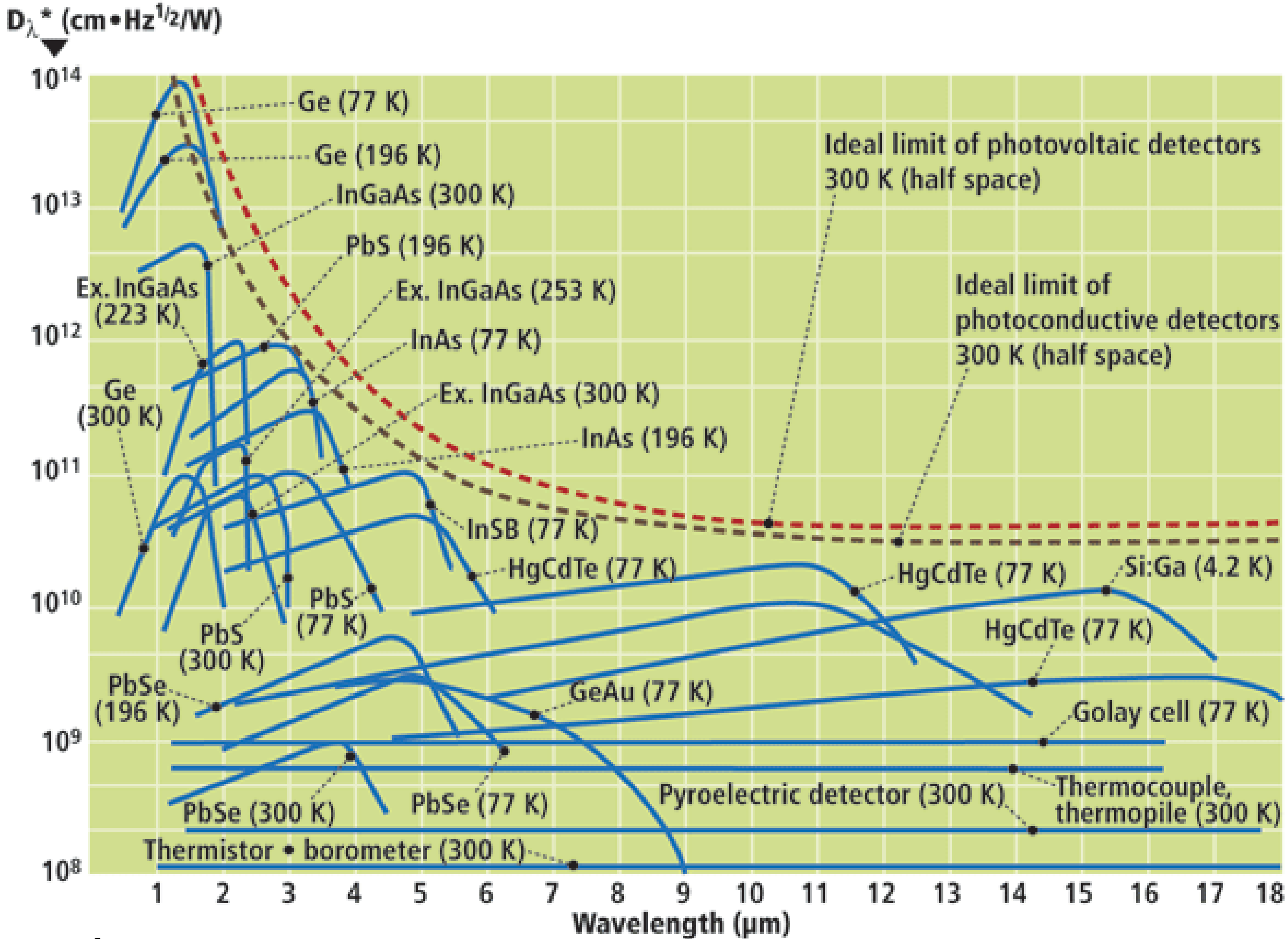
Radiometric modelling

- To determine the feasibility of a hyperspectral imager, we start with the radiometric model



- Enables us to determine key instrument parameters: detector, optical aperture, instrument altitude, spectral resolution, spectral coverage, spatial resolution

Detector Figure of Merit (D*)



[2]

[2] Courtesy of Hamamatsu

Detector Performance Limits

- Performance of detector is defined by D* ($Wcm^{-1}Hz^{-½}$)
- Current commercially available detectors
  - LWIR (8-13μm)
    - MCT: D* ~$5x10^{10}$ (LW cut off at 13μm)
    - Microbolometers: D* ~$2x10^{8}$
  - MWIR (3-6μm)
    - MCT: D* ~$7x10^{10}$
    - InSb: D* ~$1x10^{11}$
- Maximum array size: 1280x1024
- **These parameters set the physical limits of the instrument performance**

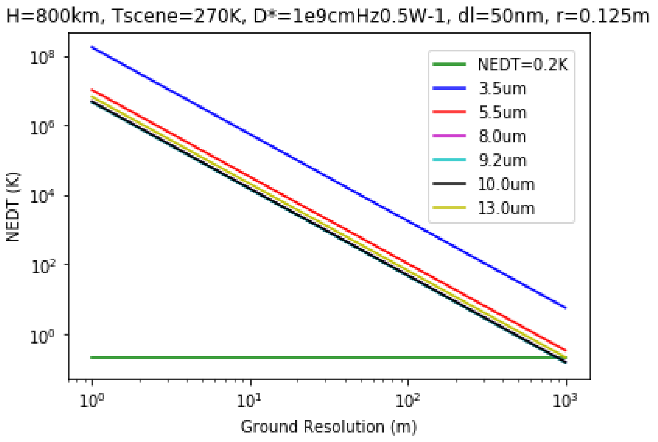
Radiometric modelling approach

- A simple radiometric model to assess the sensitivity of the instrument response to:
  - Optical aperture size
  - Altitude
  - Spatial resolution
  - Spectral resolution
- Assumptions:
  - D* is fixed for a microbolometer and an MCT
  - Reference scene temperature = 270K (typical mid point)

Trade-off parameters

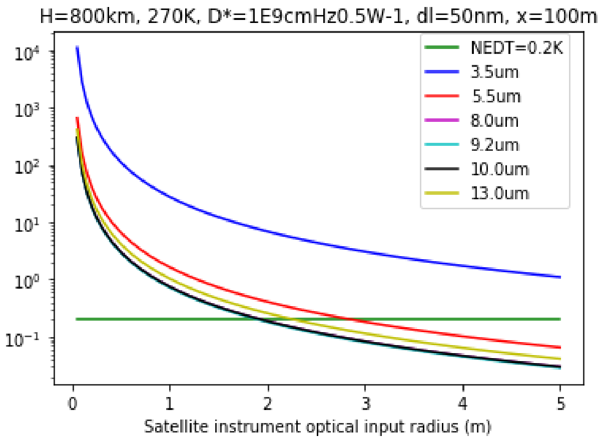
Microbolometer (D*=1x10^9 cmHz^{½}W^{-1})

Ground Resolution



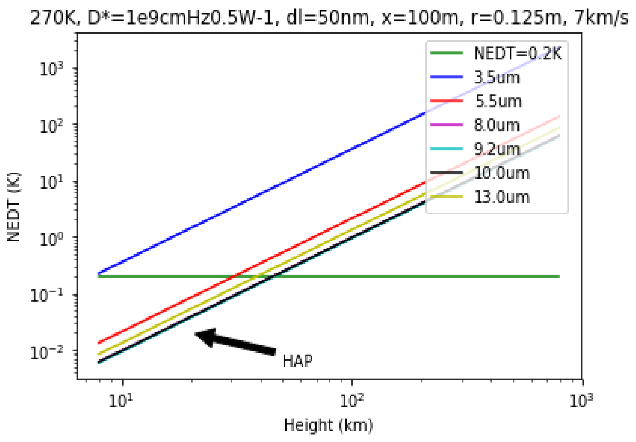
Aperture = 0.250m
Altitude = 800km

Optics Diameter



Resolution = 100m
Altitude = 800km

Altitude



Resolution = 100m
Aperture = 0.250m

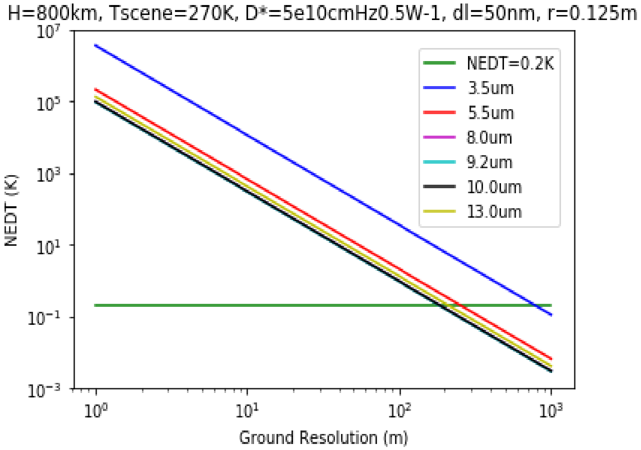
Outcomes:

- Microbolometers in LEO can not achieve required NEdT
- Yes Δλ=50nm, Δx=100m but optics diameter ≥3m
- HAPS (~22km) is an possibility

Trade-off parameters

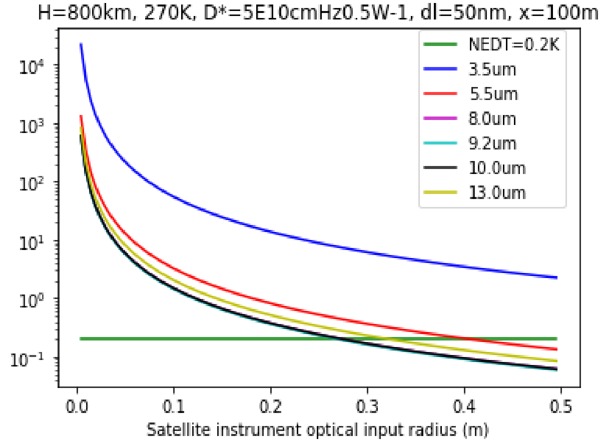
Cooled MCT (D*=5x10^{10} cmHz^{½}W^{-1})

Ground Resolution



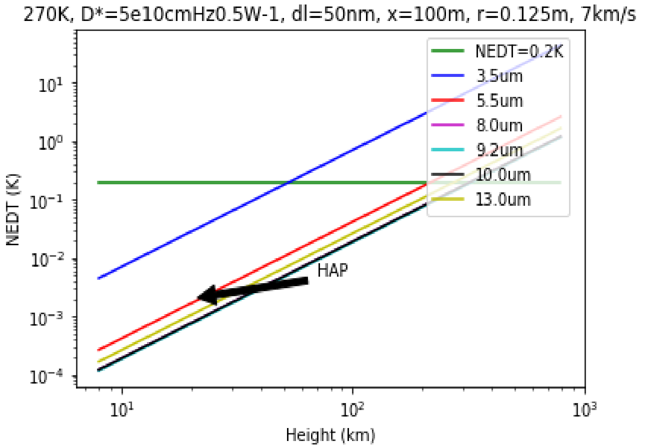
Aperture = 0.250m
Altitude = 800km

Optics Diameter



Resolution = 100m
Altitude = 800km

Altitude



Resolution = 100m
Aperture = 0.250m

Outcomes:

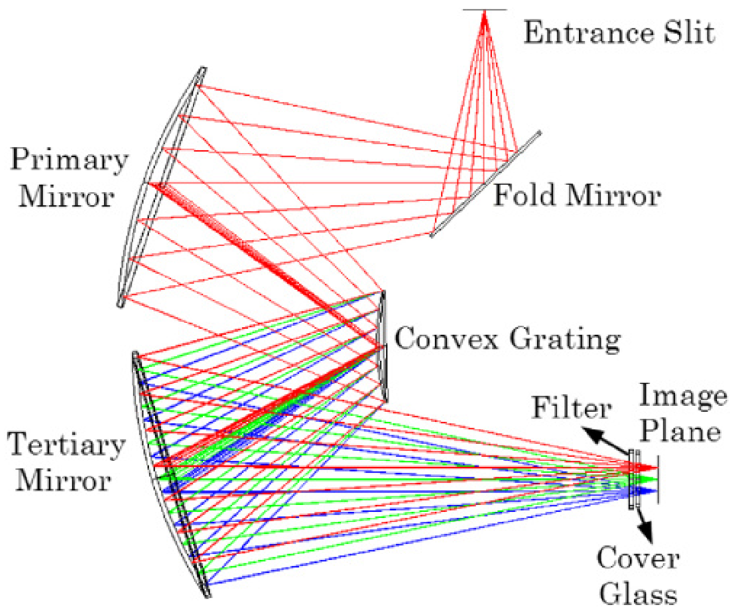
- Δλ=50nm, Δx=100m are possible but optics diameter ≥0.5m

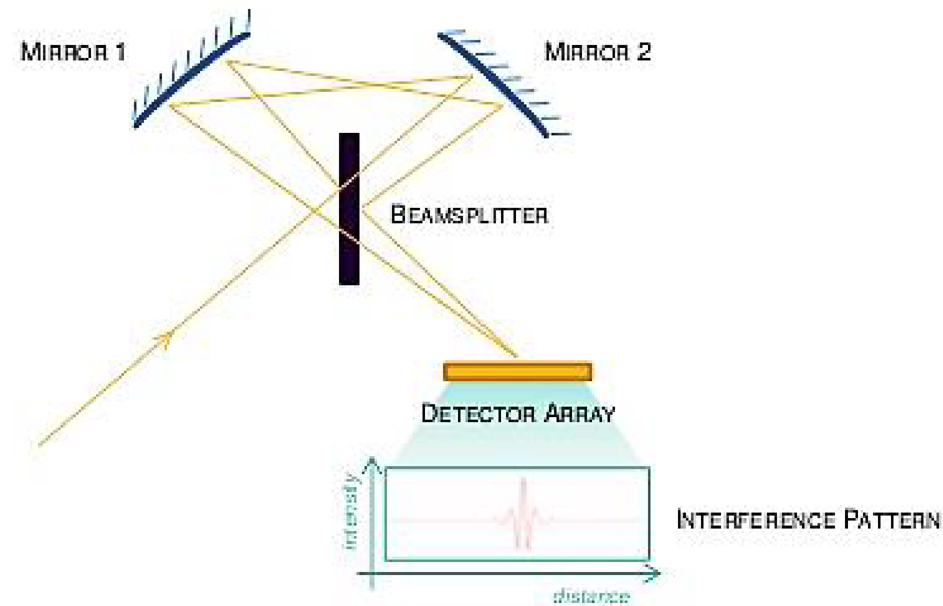
Spectral selection

- Spectral bandpass filters
  - Limited spectral coverage – not hyperspectral
- Grating spectrometers
  - Hyperspectral possible – grating design / spectral range
- Fourier Transform spectrometers
  - Moving mirror (Michelson type)
  - Static FTS
- Dispersive spectrometers
  - Susceptible to chromatic aberration, limited spectral range

Proposed spectrometer concepts

	Offner	microFTS
Principle	Reflective optics/grating	Static Fourier Transform (FT)
Throughput	Low (slit)	High (array limited)
Challenges	Multiple detector arrays for high spectral range/resolution	Resolution limited by detector pixel array and density
Binning spectral/spatial	Trade off spatial/spectral resolutions	Post processing FT trade off





Summary

Many science drivers require high spectral and spatial resolutions

Existing instruments don't meet future requirements/specifications

Physical limitations of detector performance and trade-off parameters

Proposed TIR imaging spectrometer concepts

- HAPS: high ground resolution and normal optical input diameter
- Split concept (MWIR/LWIR): orthogonal imaging spectrometers
- Binning: sample at threshold values, bin spatial or spectral data

Wait!

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Technology Roadmap

1. **Trade off study between Offner and microFTS**
   - Down select based on optical analysis
   - Identify key technology constraints
2. **Develop breadboard instrument concept**
   - Demonstrate performance in laboratory
   - Field testing
3. **Prototype airborne instrument**
   - Flight test UAV/airplane/HAP and compare results
4. **Satellite instrument**
   - Phase 0/A studies, Earth explorer or Copernicus missions

Thank you for your attention

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