Limb Imaging Aerosol Distributions from a Stratospheric Balloon

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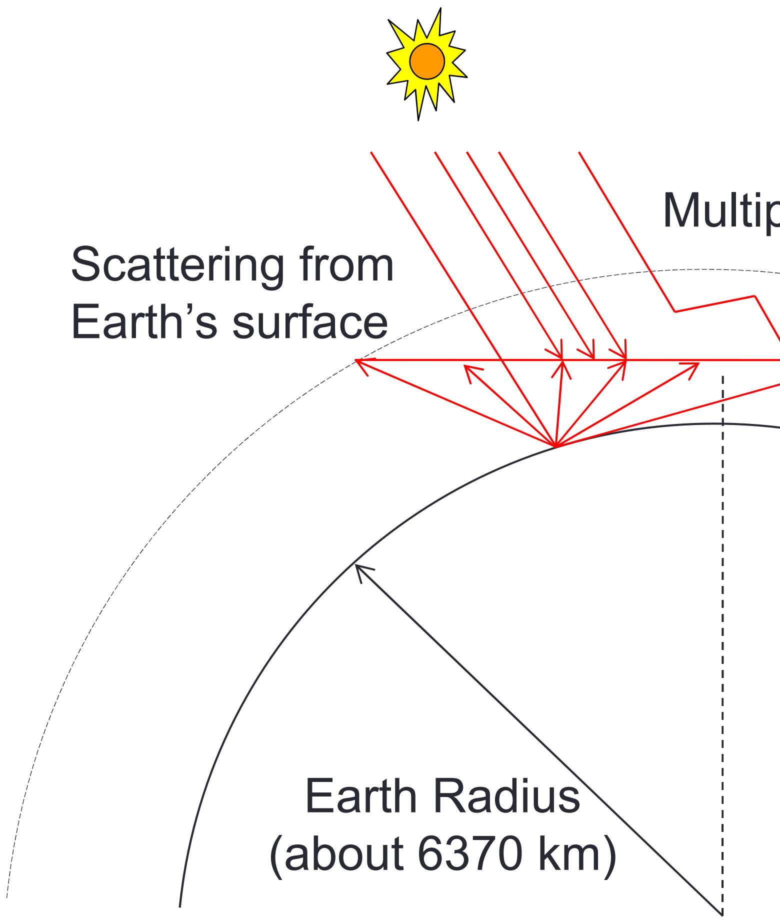
LIMB-13
This presentation participates in the student award contest

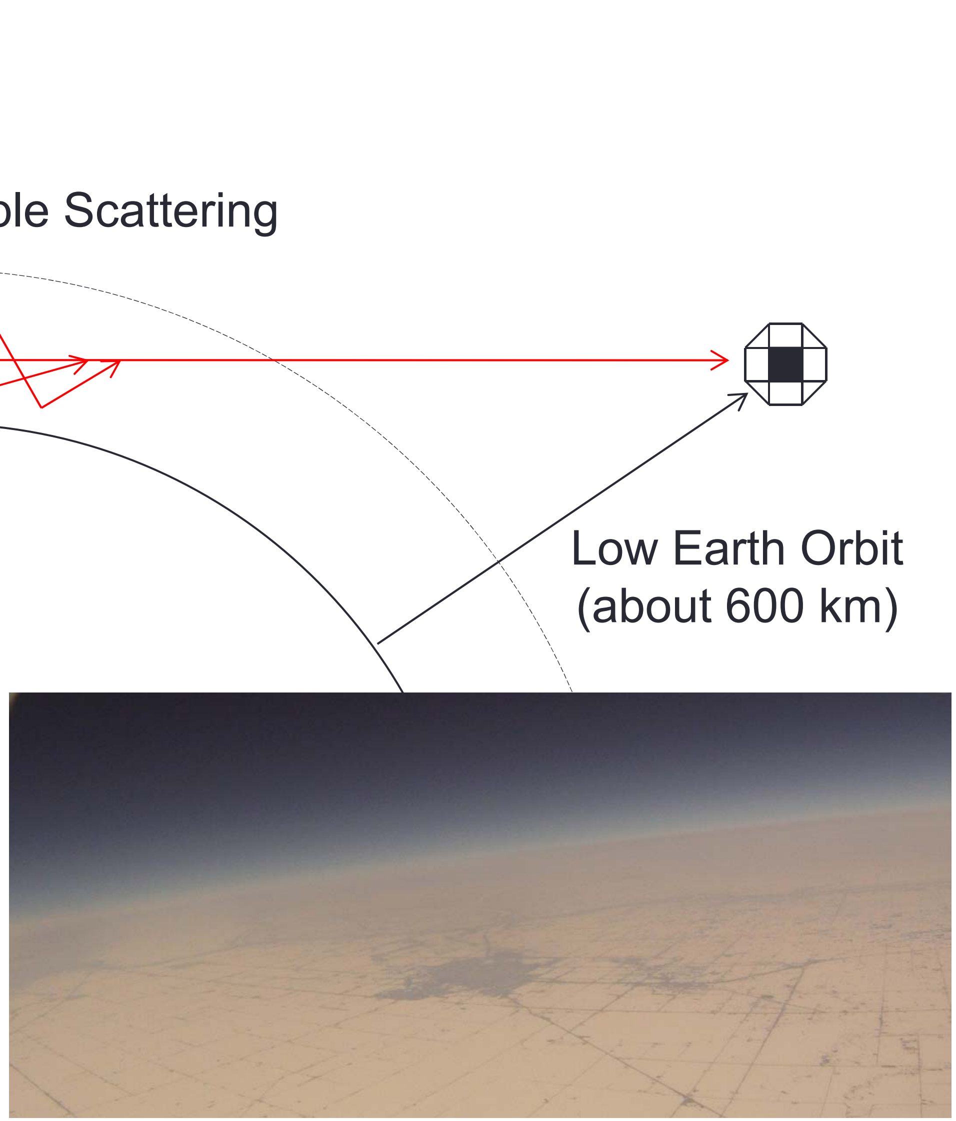
Outline

- The limb scatter measurement technique
- Aerosol in the Upper Troposphere and Lower Stratosphere (UTLS)
- The need for higher resolution
- Development of Aerosol Limb Imager (ALI)
    - Funded by the Canadian Space Agency FAST program
    - Prototype of potential future satellite imager
    - Acousto-optical tunable filter technology
    - Optical design development
- Planned CSA/CNES flight campaign 2014

Limb Scattering

A measurement of the intensity of sunlight scattered from the atmosphere





Sensitivity to vertically and optically thin layers due to long horizontal line-of-sight

- **Focus on measurements of two aerosol types:**

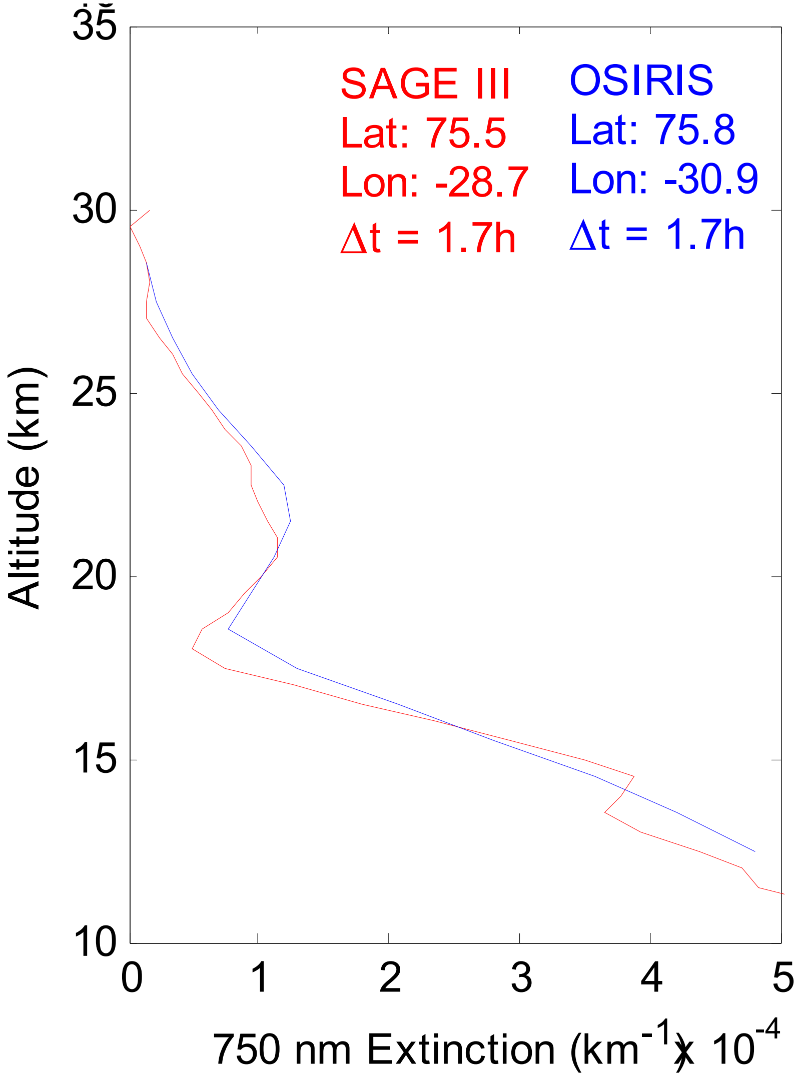
(1) Stratospheric aerosol

- Sub-micron liquid sulphate (H_2SO_4/H_2O)
- From by oxidation of tropospheric sulfur gases
- **Volcanic**, biogenic, anthropogenic
- Radiative cooling by scattering incoming solar radiation

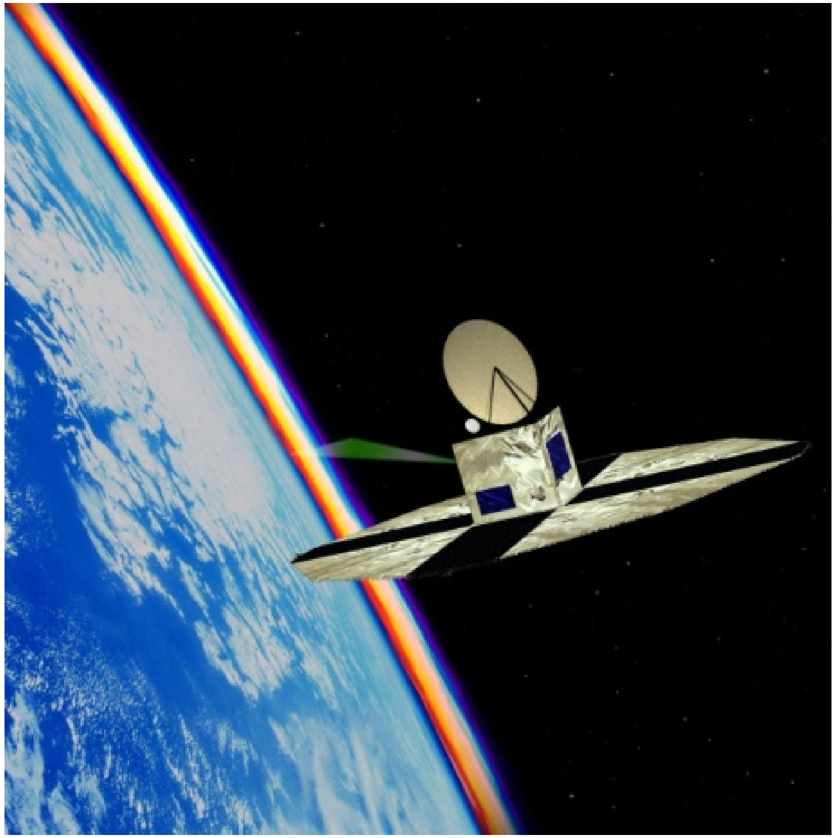
(2) Sub-visual cirrus

- High altitude ice crystal clouds
- Very thin – optically and vertically
- Vast horizontal extent, particularly in the tropics
- Significant effect on global energy balance (visible and thermal)
- Linked to stratospheric water vapour

Coincident measurements



OSIRIS



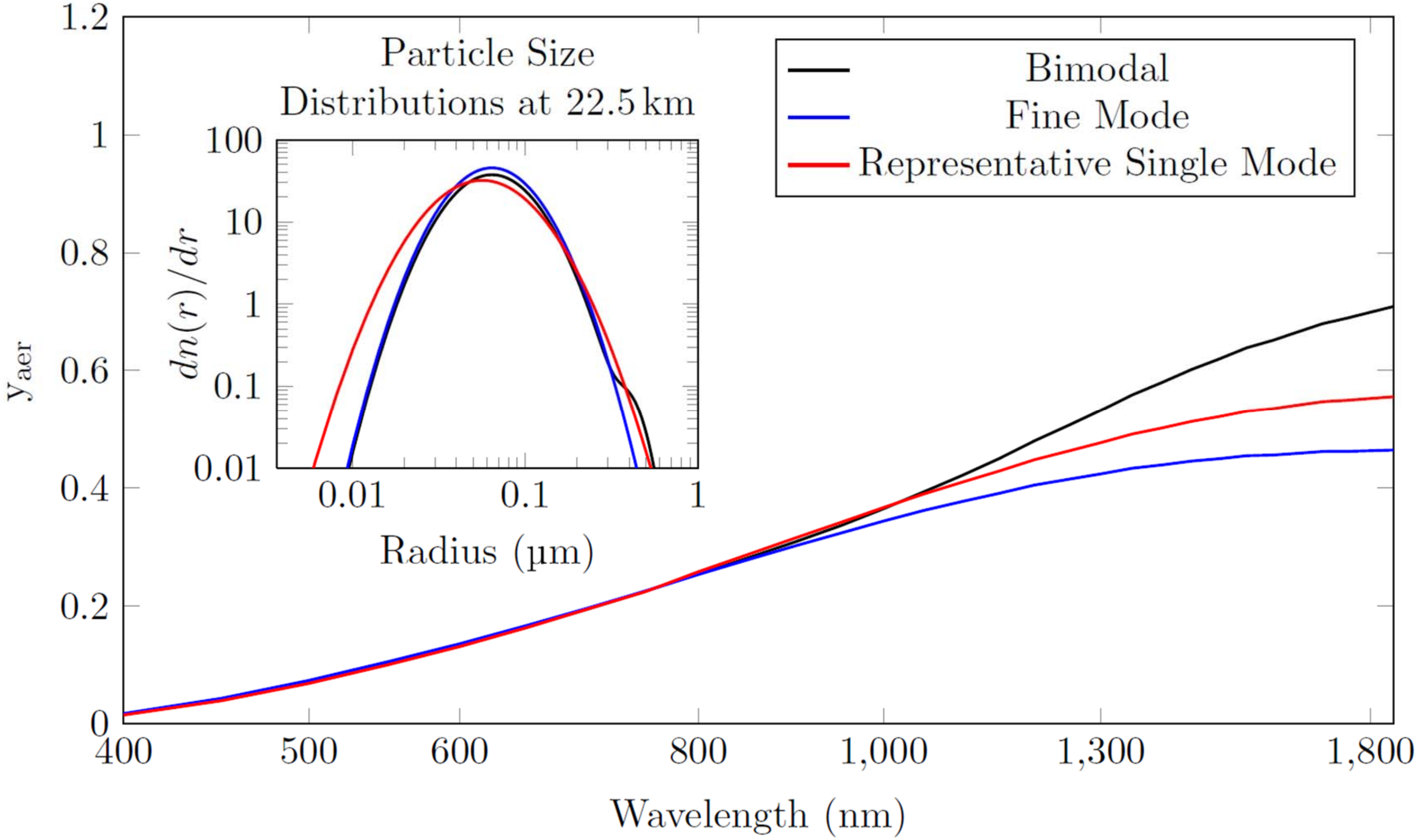
Scientific Needs for the Future

- **Current satellite capabilities (OSIRIS and SCIAMACHY)**
    - Scanning spectrographs
        - Single line-of-sight, relatively high spectral resolution
    - 2 to 3 km vertical resolution
    - Approximately 500 km horizontal resolution (along track)
    - Wavelength ranges UV to NIR

- **UTLS aerosol measurement requirements for the future**
    - Vertical resolution target: 200 m
        - Structures less than 500 m
    - Horizontal resolution target: 50 km along track
        - Structures less than ~10's of kilometers
        - Tomographic inversion
    - Wavelength resolution target: 5 to 10 nm
        - Broadband aerosol scattering does not require high res
    - Polarization measurements – aerosol type discrimination
    - Wavelength range: →→

Scientific Needs for the Future

- Assume a bi-model stratospheric aerosol true state
- Forward model radiances as simulated measurements
- Retrieve extinction with different assumed size distributions
- Compare resulting measurement vectors



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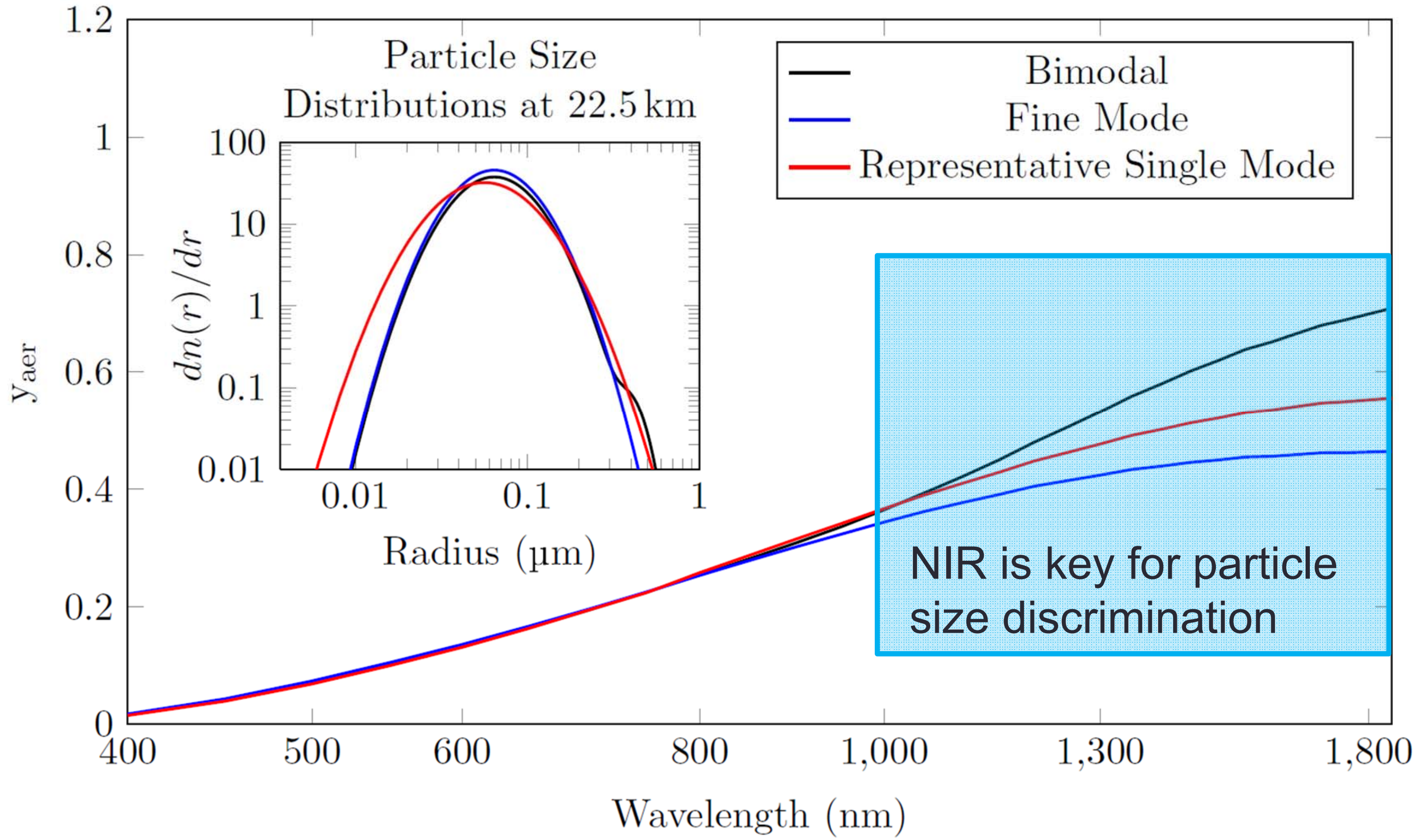
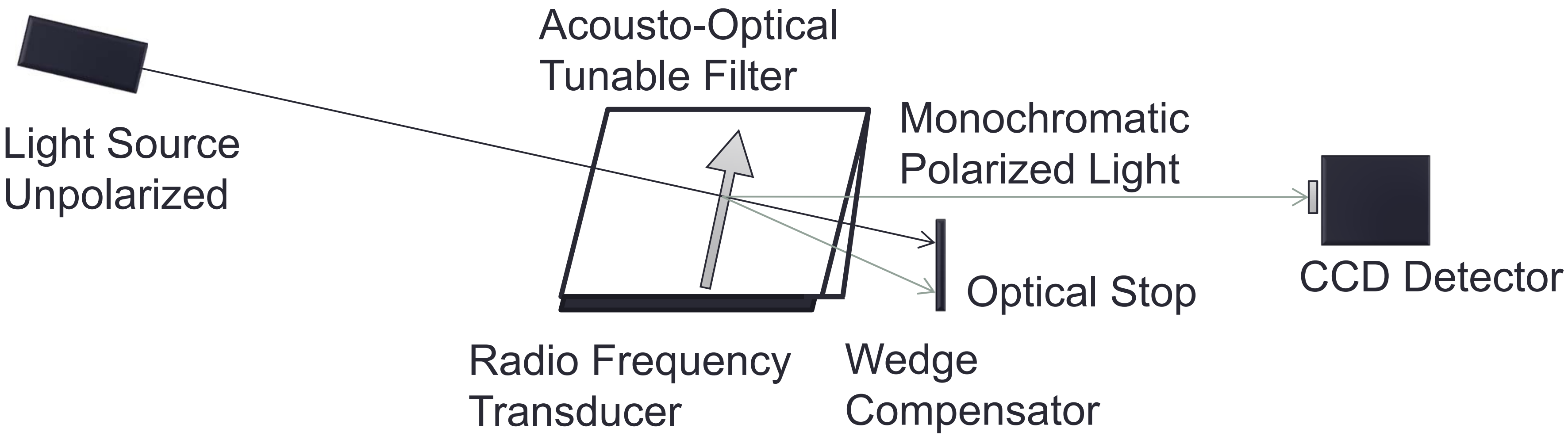


Aerosol Limb Imager Prototype

- Two dimensional spatial imager
  - 2D image at a narrow wavelength passband
  - Rapidly scan the wavelength for successive images
- Acousto-optical filter technology
  - Similar to ALTIUS design concept
  - Tunable over one octave
    - Chosen prototype wavelength range: 600 – 1200 nm

- This wavelength range provides
  - Ease of prototyping (visible range)
  - Some particle size/type sensitivity
  - Difficulty in detector technology
    - no single detector to cover the range
    - Currently using silicon CCD for 600 – 900 nm range
    - Investigating an InGaAs array for long wavelengths

Acousto-Optical Tunable Filter



A general AOTF experimental layout with all major components in the optical chain

Relation between the Radio Frequency (RF) of the standing wave in the crystal, F, and the incidence angle of the light, θ_i to the diffracted wavelength, λ:

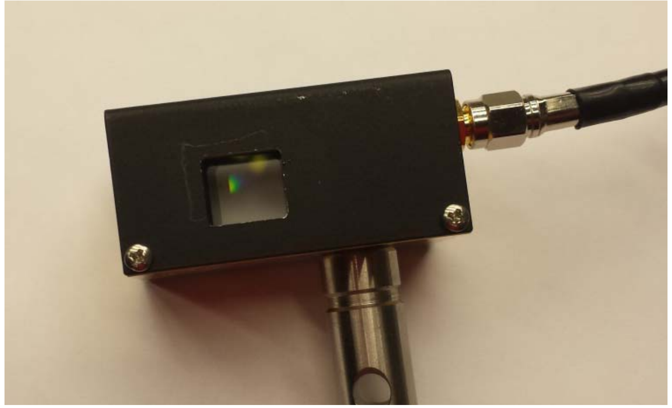
$$\lambda = \frac{\Delta n \nu}{F} \frac{\sin^2(\theta_i + \alpha)}{\sin \theta_i}$$

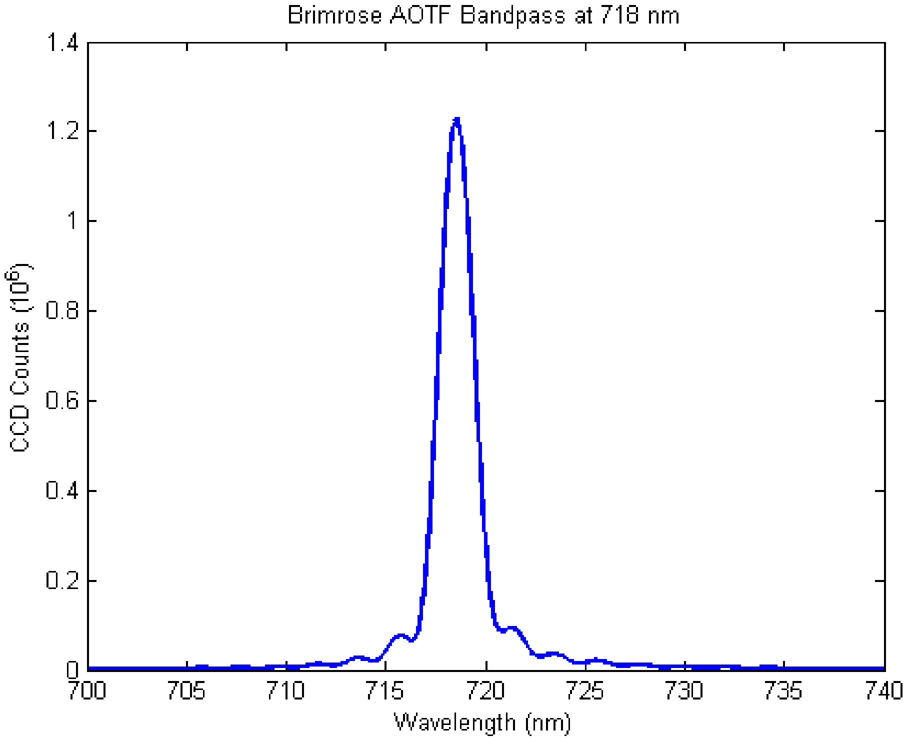
Where the change in index of refraction, Δn, acoustic velocity, v, and cut angle, α, are all constants for a given AOTF.

Brimrose Acousto-Optical Tunable Filter

Brimrose Corporation AOTF specifications:

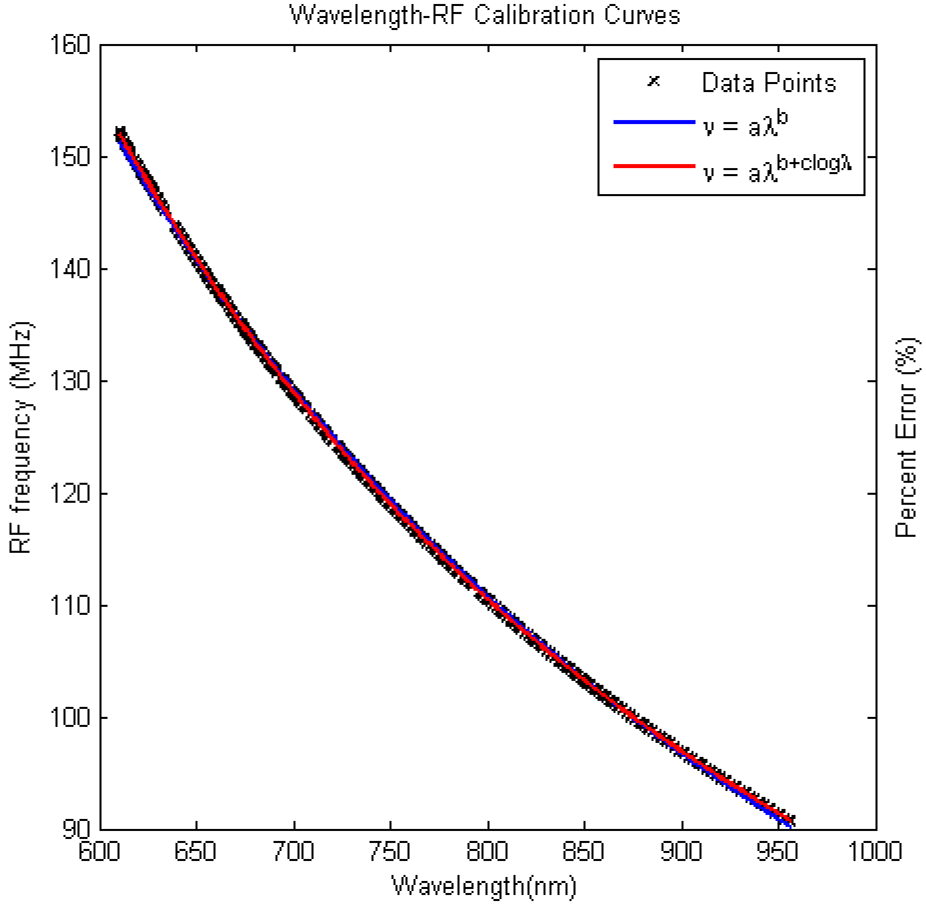
- 600-1100 nm wavelength range
- Tellurium Dioxide substrate
- 10x10 mm optical aperture
- 4.6 degree angular aperture
- Spectral resolution
    - 1.6 nm at 641 nm
    - 4.6 nm at 1048 nm
- 60% diffraction efficiency throughout operating range
- RF range of 75-156 MHz
- 2 W RF driving power

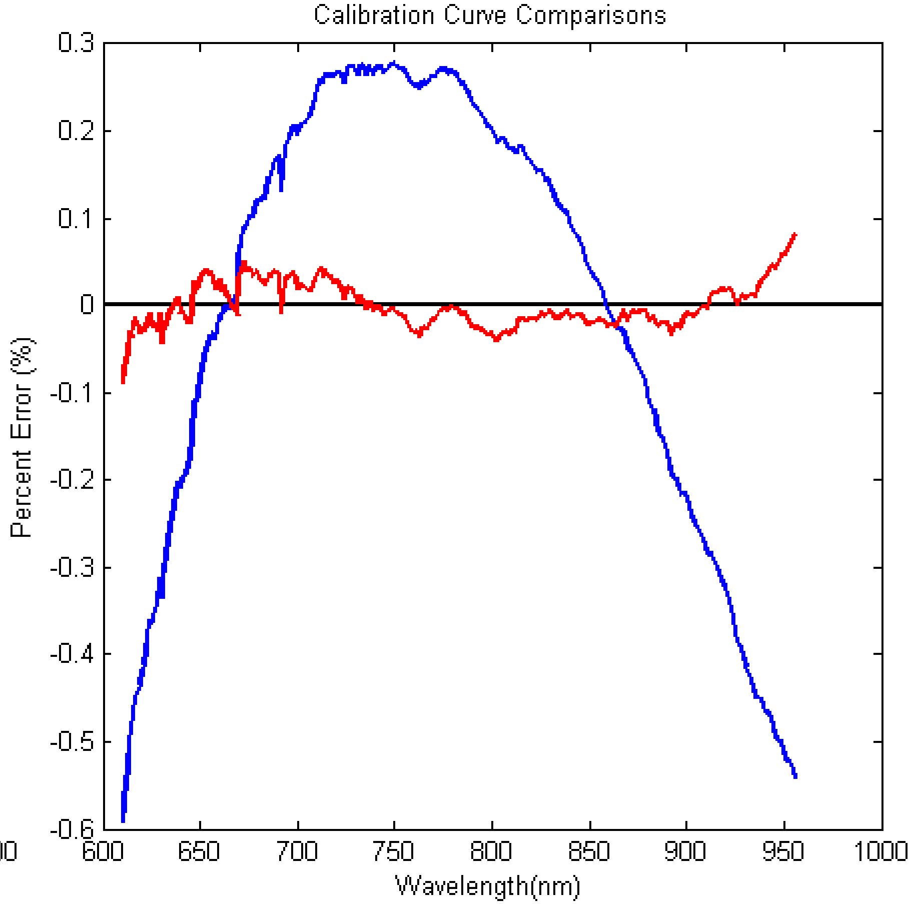




Brimrose Acousto-Optical Tunable Filter

Measured RF calibration curves

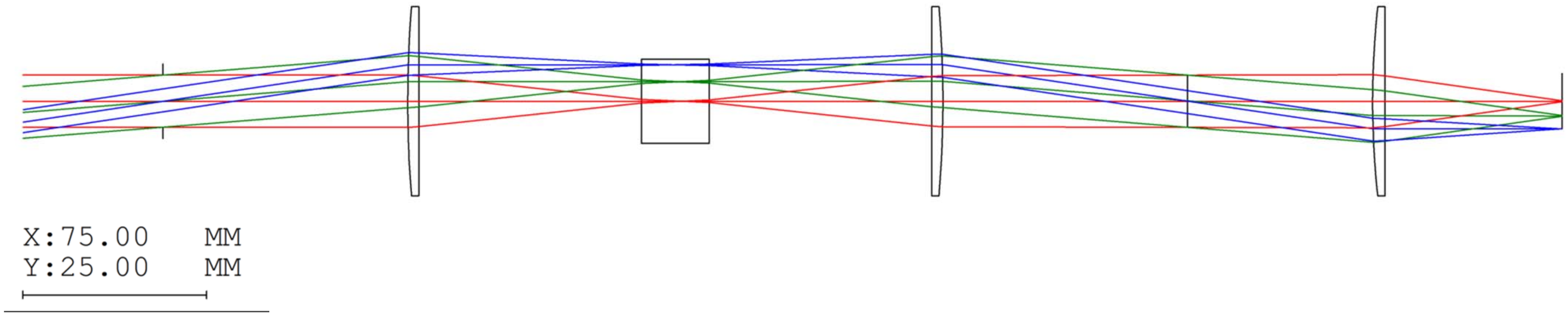




Telecentric Design

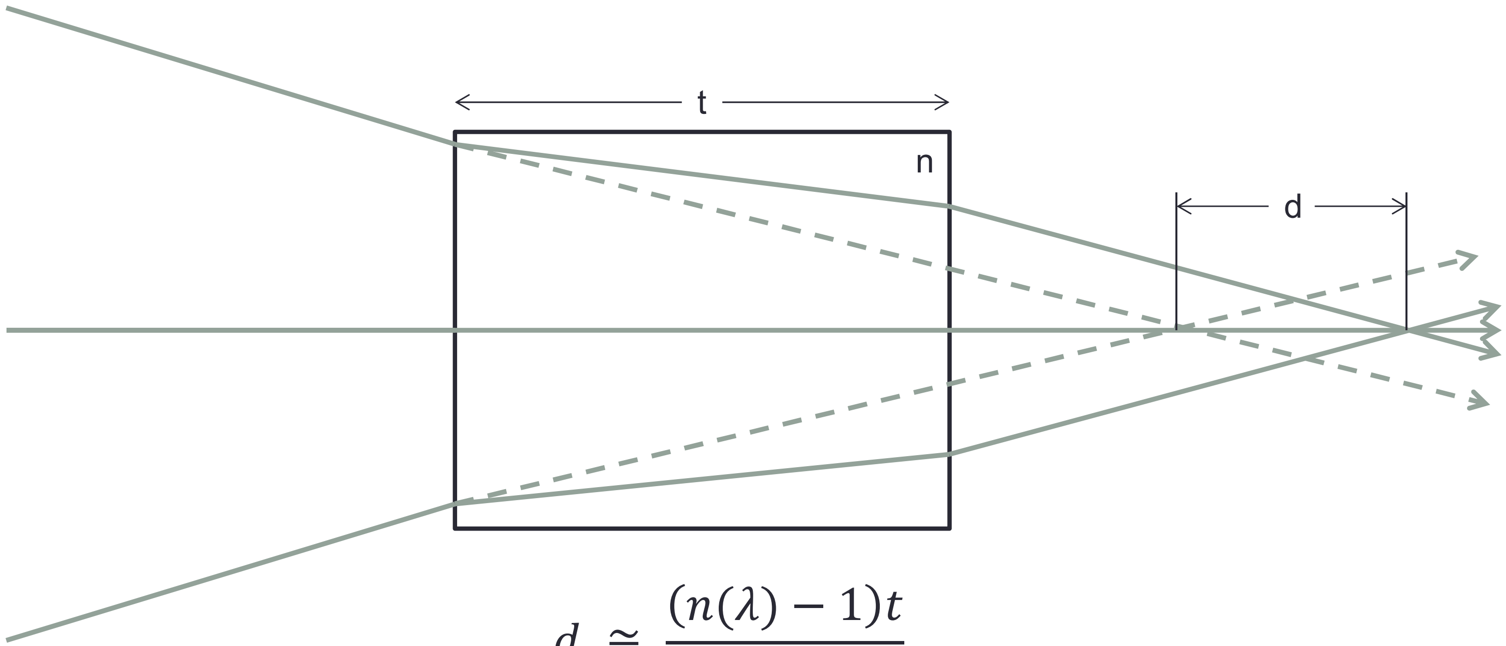
Pros:
- No spectral gradient on the recorded image
- No magnification effect caused by a change in wavelength

Cons:
- Creating a diffraction limited system for a number of wavelengths is difficult
- A blurring effect occurs when the wavelength is changed
- Larger spectral bandpass



Prototyped telocentric system used for testing the optical layout. System was built in Code V and in the lab and tested.

Telecentric Design



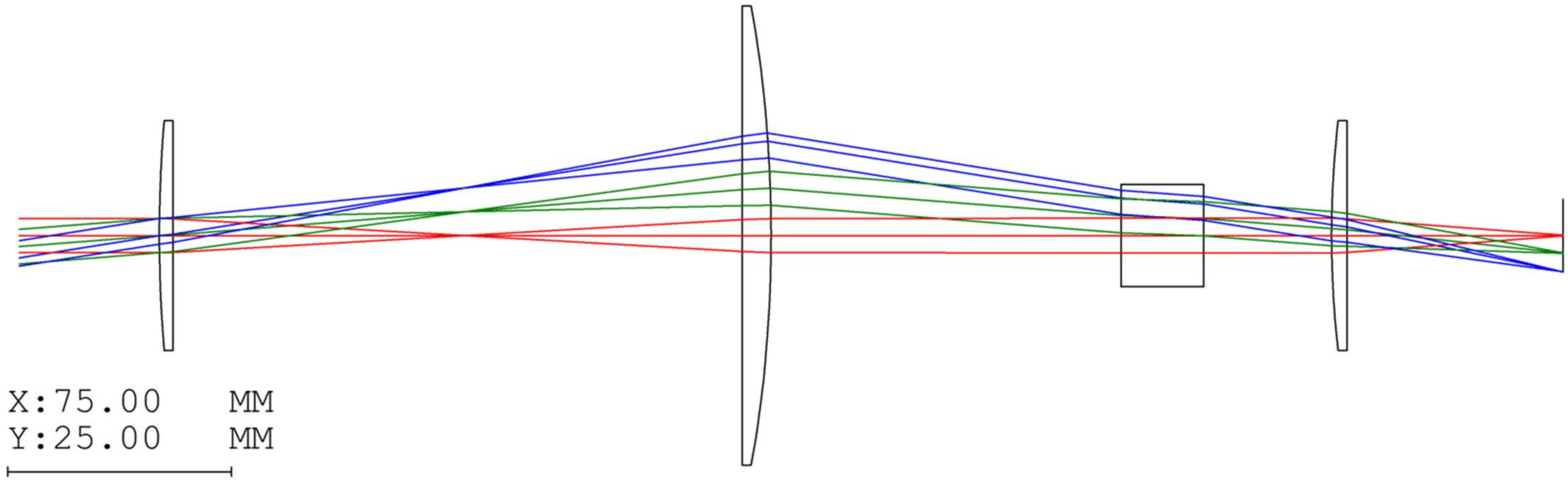
$$d \cong \frac{(n(\lambda) - 1)t}{n(\lambda)}$$

- The AOTF TeO2 crystal is highly dispersive
- Focused light – different wavelengths have different optical paths
- Location of the focal plane changes with wavelength

Telescopic Design

Pros:
- Higher resolution image can be achieved
- The image plane does not greatly move with respect to wavelength
- The filtered wavelength have a smaller bandpass

Cons:
- A spectral gradient appears on the final image
- A small wavelength dependant magnification occurs with respect to wavelength



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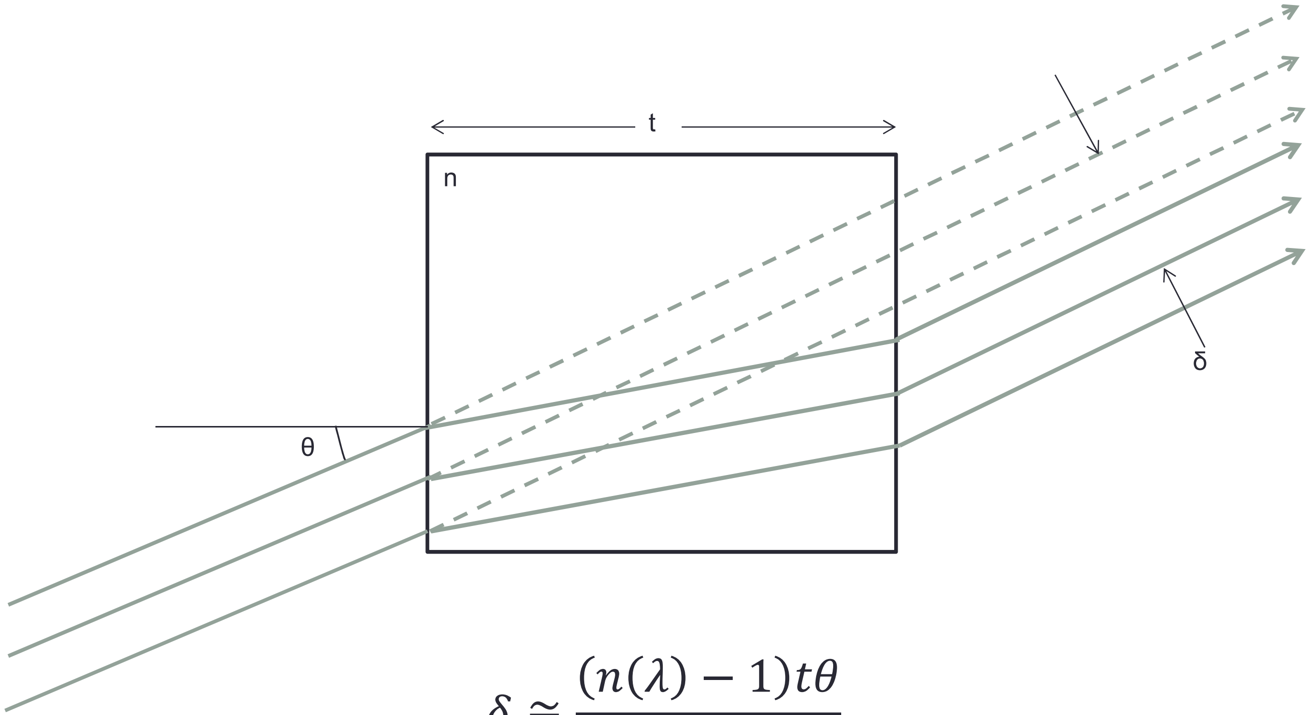
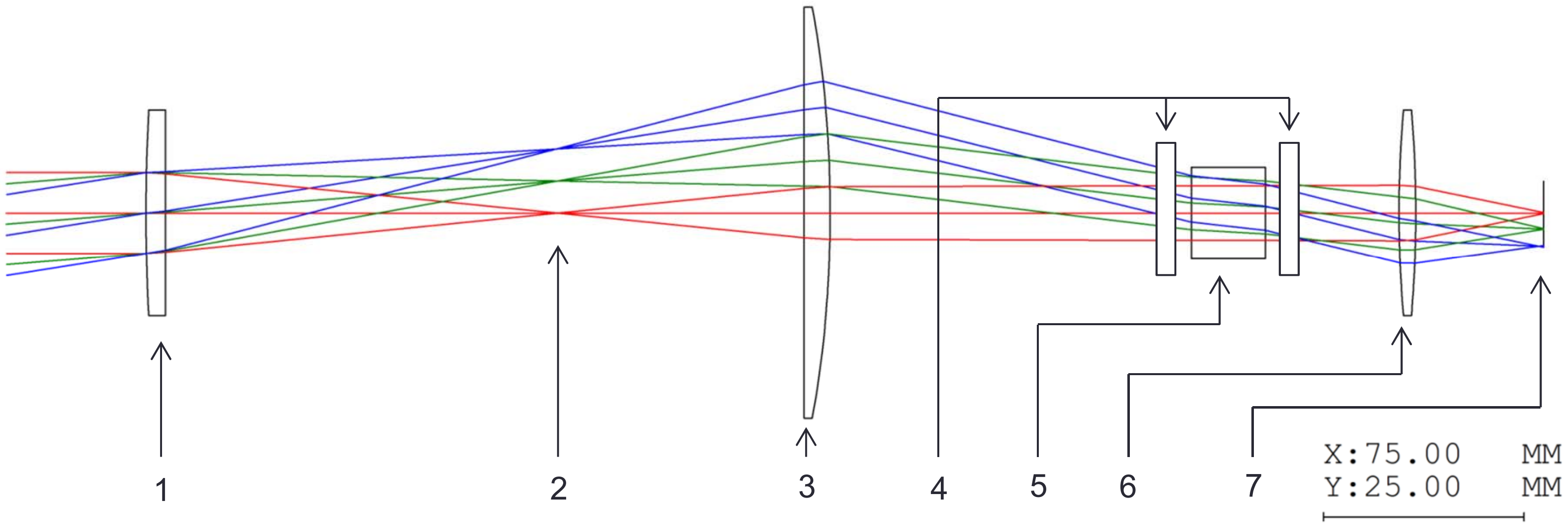


$$\delta \cong \frac{(n(\lambda) - 1)t\theta}{n}$$

- The AOTF TeO2 crystal is highly dispersive
- The location of the collimated light varies with wavelength
- Results is slight change in magnification in the final image

Final Choice: Telescopic Optical Design

- Final design decision: Telescopic
  - The wavelength gradient not a concern for broadband scattering
  - No movement of focal plane
- Essential choice: spatial over spectral resolution



Current optical design of the ALI instrument including linear polarizers and optical stops

1. 150 mm Plano-Convex Lens
2. Field Stop
3. 100 mm Plano-Convex Lens
4. Linear Polarizers
5. AOTF
6. 50.4 mm Bi-Convex Lens
7. CCD Detector

F/number	7.5
Field of View (degrees)	6.0x6.0
Effective focal length (mm)	75.4

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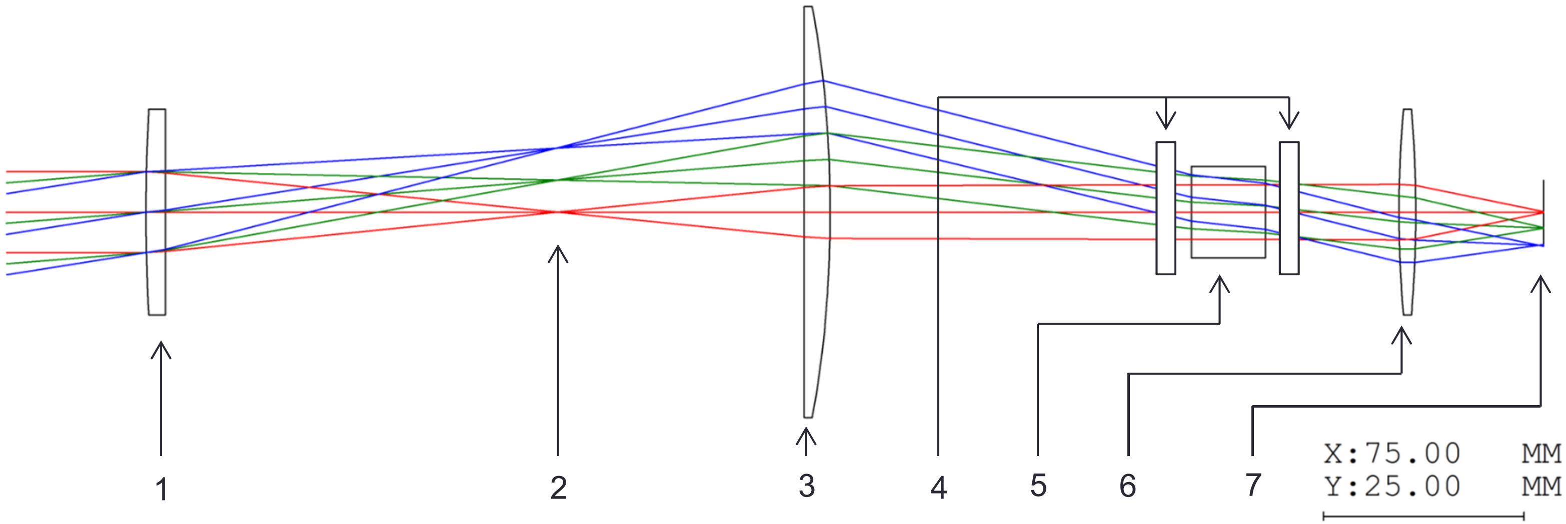

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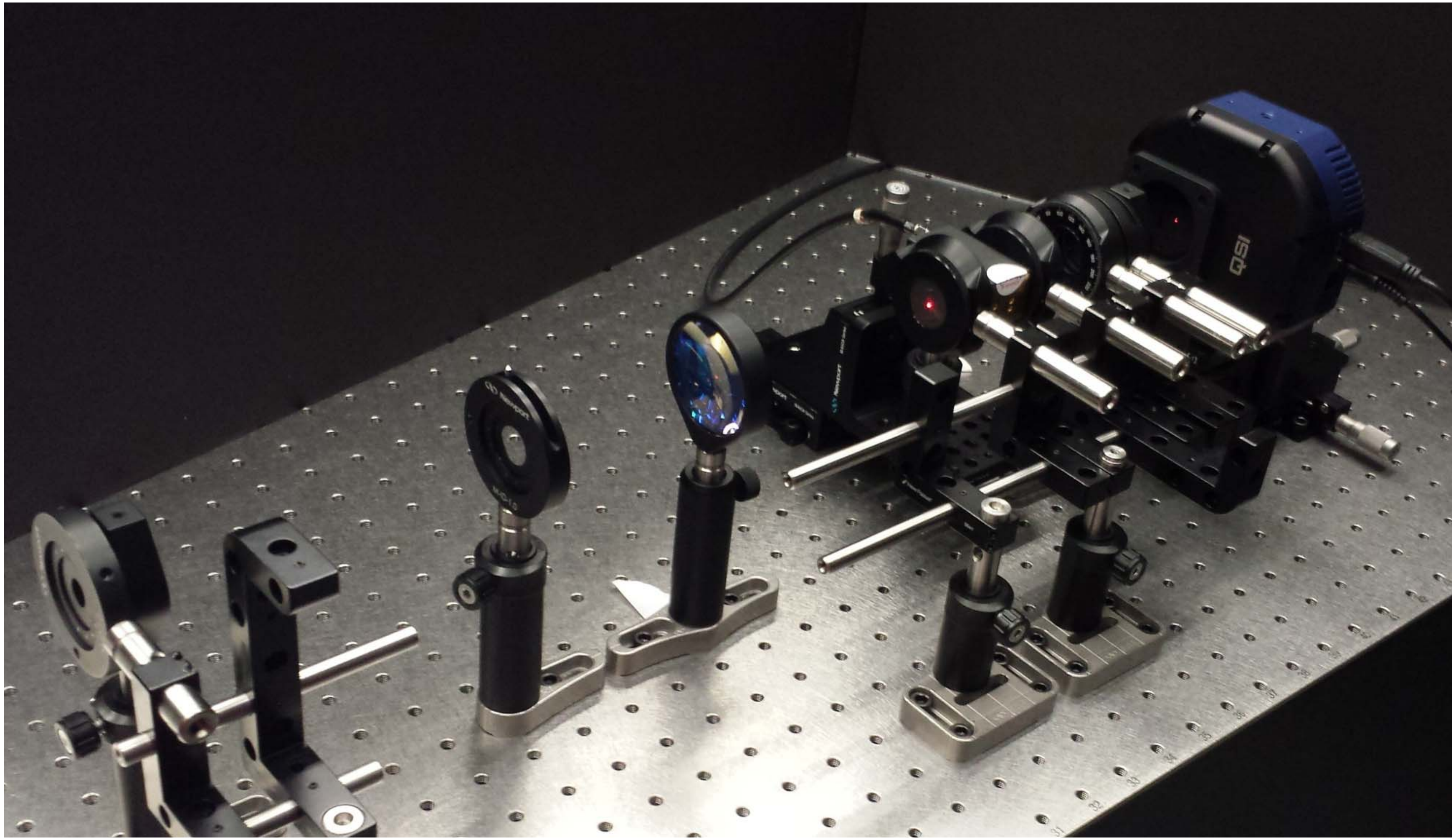
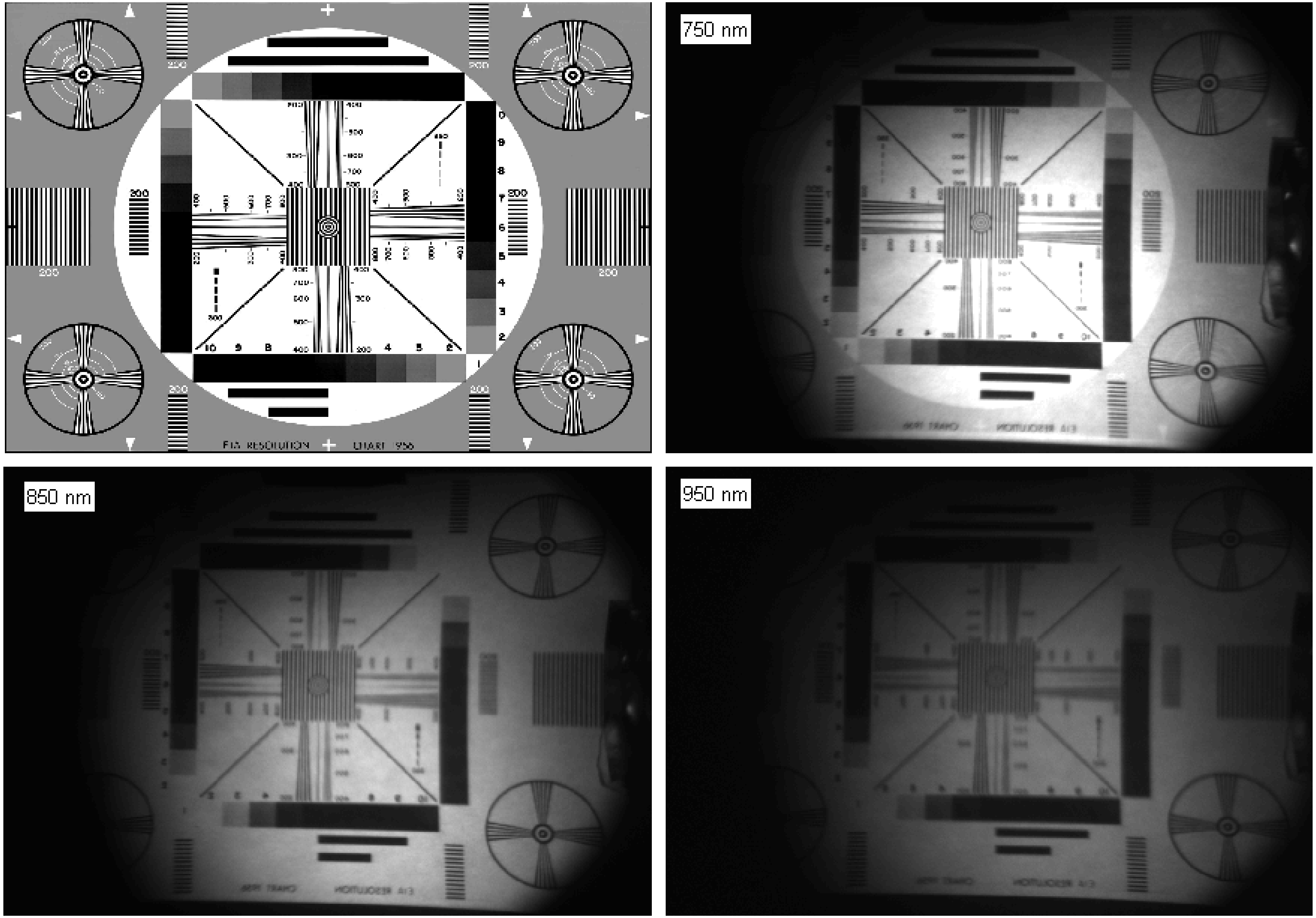
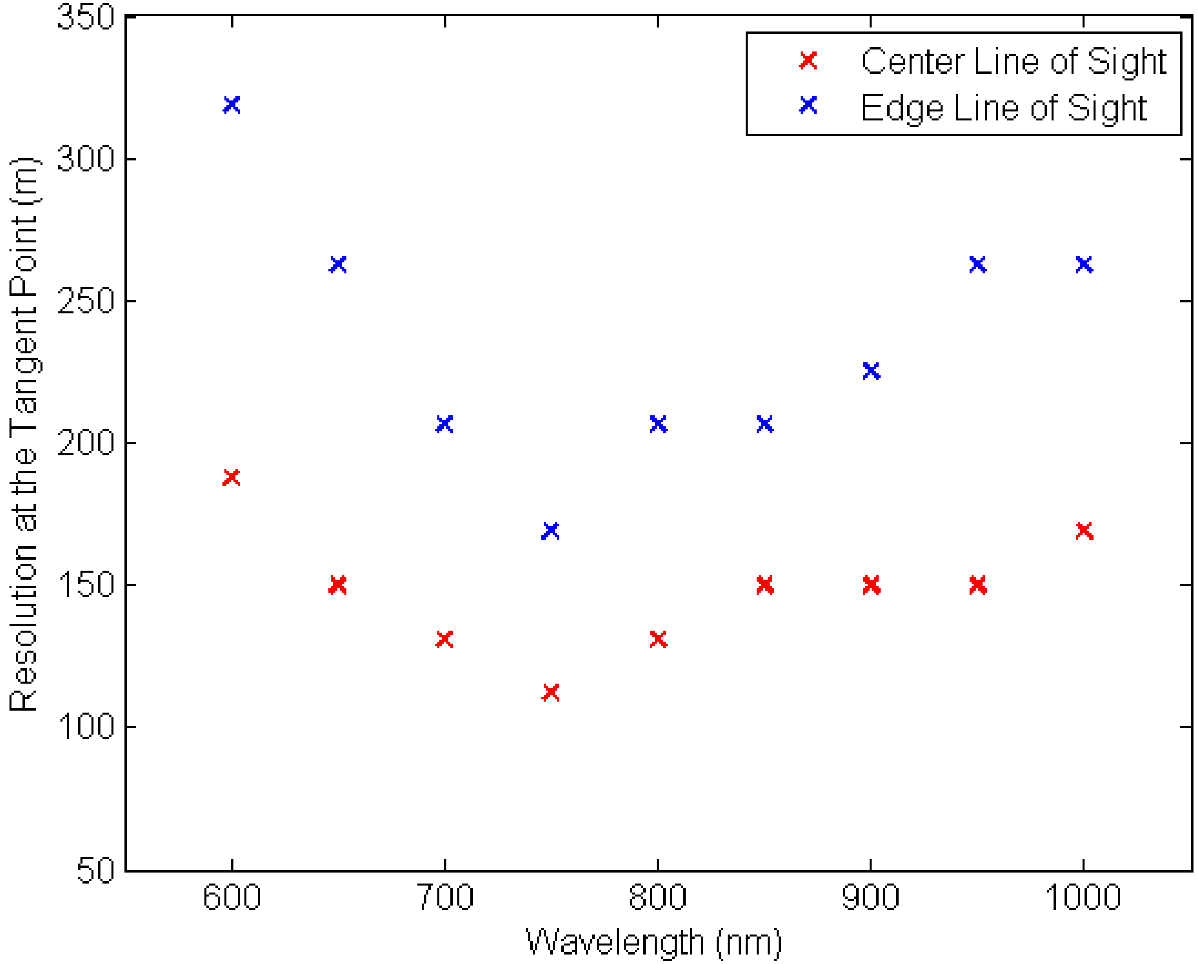
Ground to horizontal from 35 km balloon float altitude

Optical Table Breadboard ALI Prototype



Imaging Target Resolution Comparison





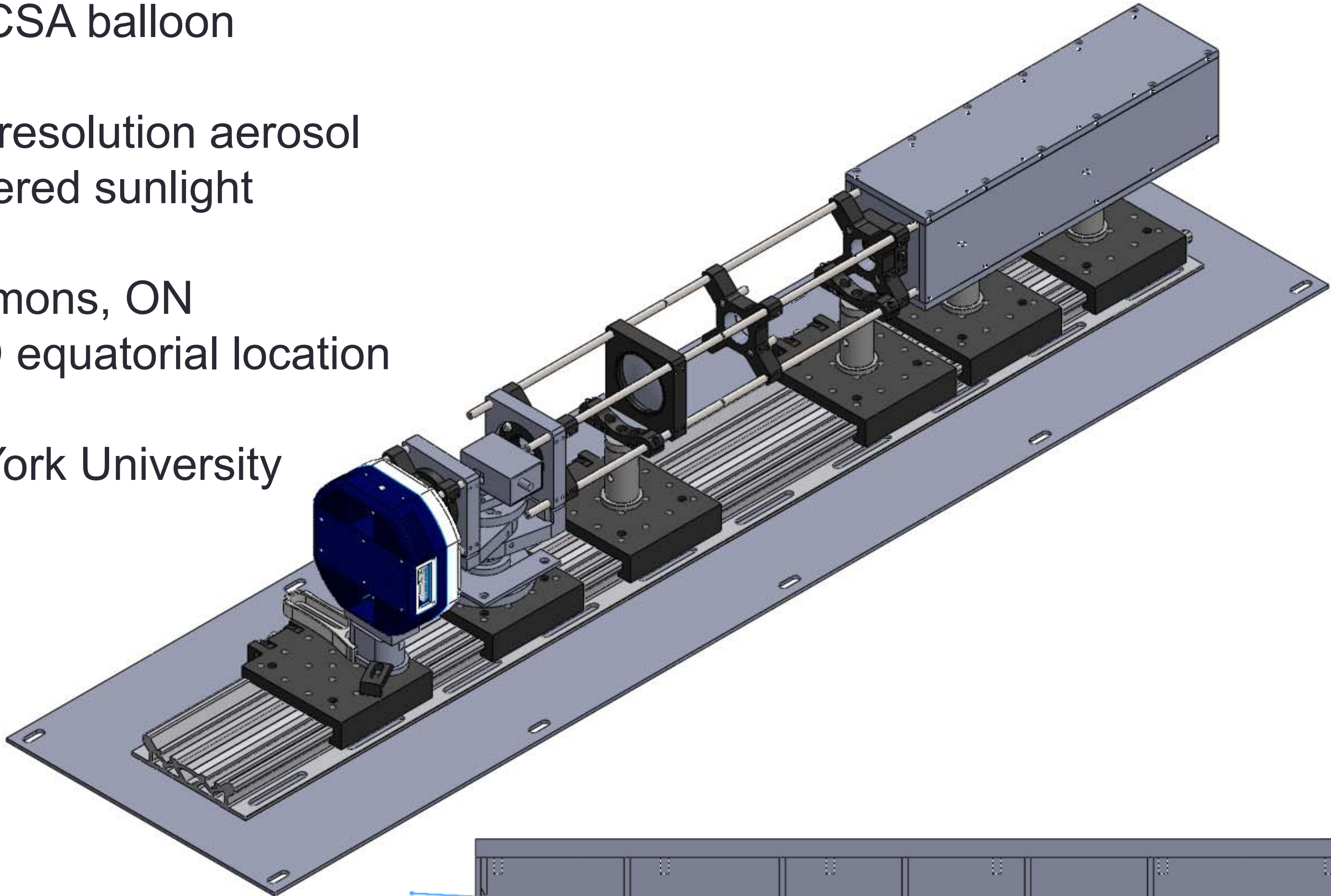
Approximate tangent point resolutions for balloon-borne geometry using lab resolution target measurements

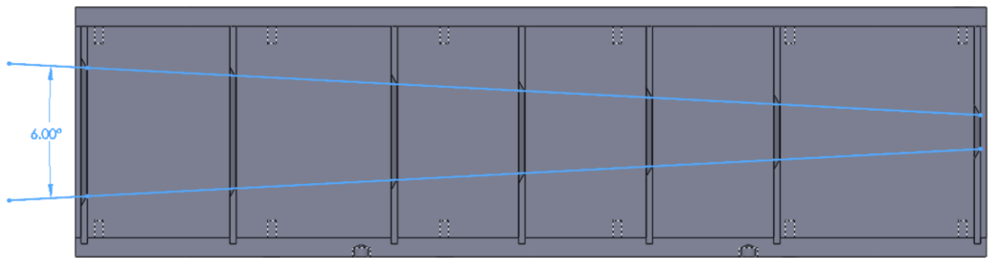
Platform: CNES/CSA balloon

Goal: High spatial resolution aerosol imaging from scattered sunlight

Flights: 2014 Timmons, ON
2015 TBD equatorial location

Collaborations: York University





Summery

- Prototyping an instrument for a stratospheric balloon platform.
- Purchased and calibrated a Brimrose AOTF which filters light in between 600-1200nm.
- Two optical designs prototyped and tested in the lab and using CODE V optical design software.
- Telescopic optical system chosen for ALI for better spacial resolution over spectral resolution.
- Flight model currently being built with a planned launch in Timmons ON in 2014.

Thank You
Any Questions?