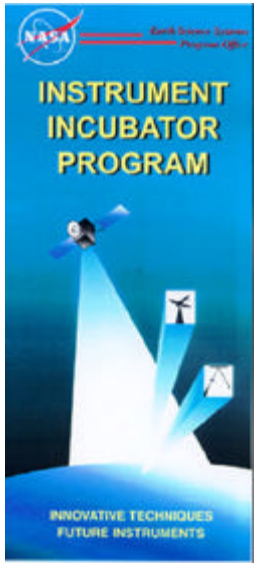
Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA)

Midphase Data Review Package

August 18th, 1999



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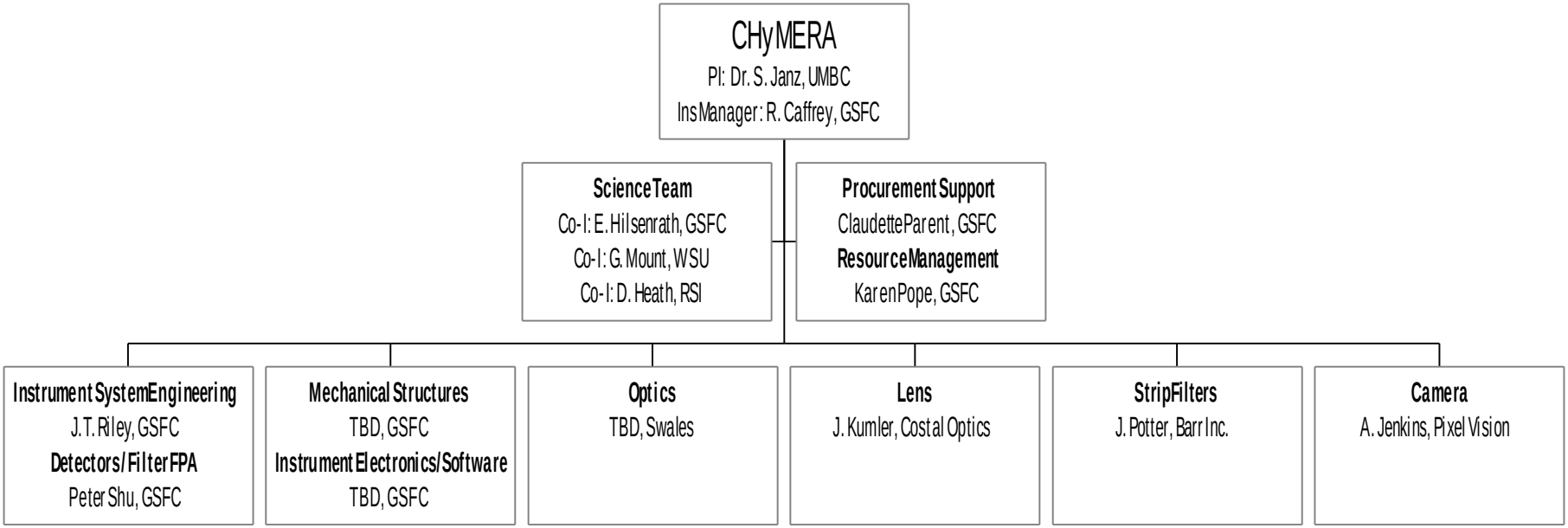
Research Support Instruments

CHyMERA Organizational Chart

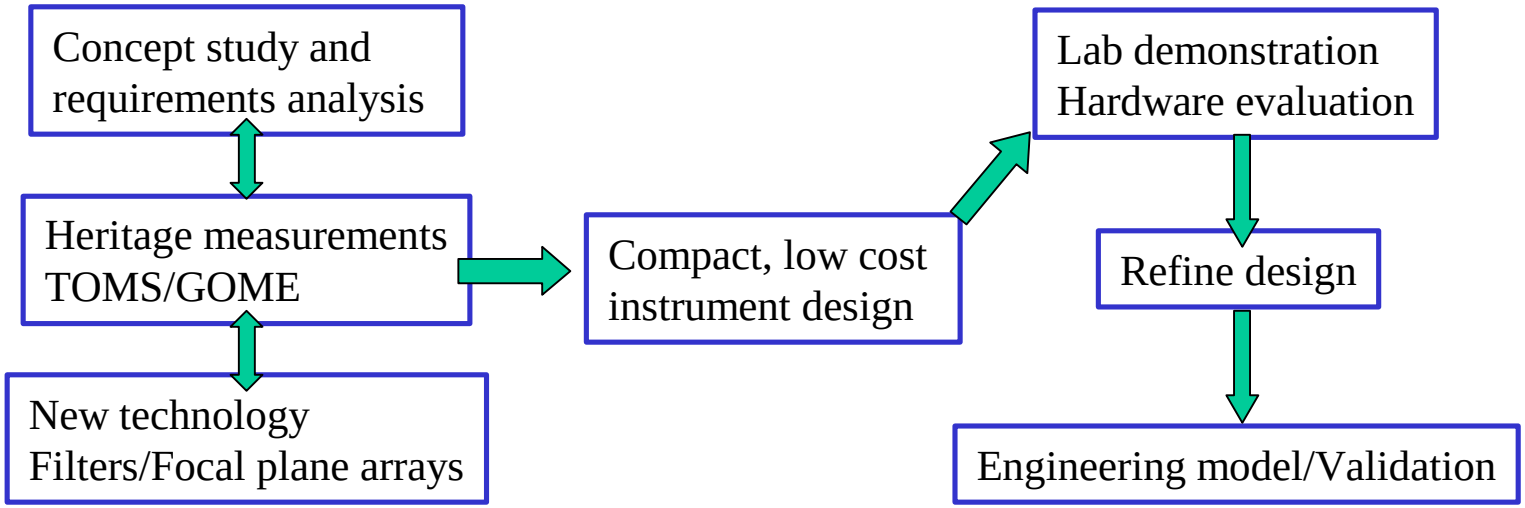


Outline

- Overview of project
  - Project status summary
- Requirements and sensitivity analysis results
  - NO_2 sensitivity analysis results
  - SO_2/O_3 sensitivity
  - Signal-to-noise calculations and spatial resolution
  - Summary of sensitivity analysis
- Hardware status review
  - Filter array design
  - Wide-field optics design
  - Detector system status
- Costs summary
- Project schedule

Concept overview

- Use development of stable interference filters to design compact, low cost imaging filter radiometer.
- Improve on state-of-the-art through careful selection of filter channels.
- High quality imaging system + CCD will enable high spatial resolution measurements of atmospheric trace gases.
- Demonstration instrument will target retrievals of NO_2, O_3, SO_2, and UV reflectivity/aerosol studies.



Project Status Summary

- Requirements analysis milestone complete.
  - A requirements analysis was completed to define the performance characteristics needed for hardware specifications.

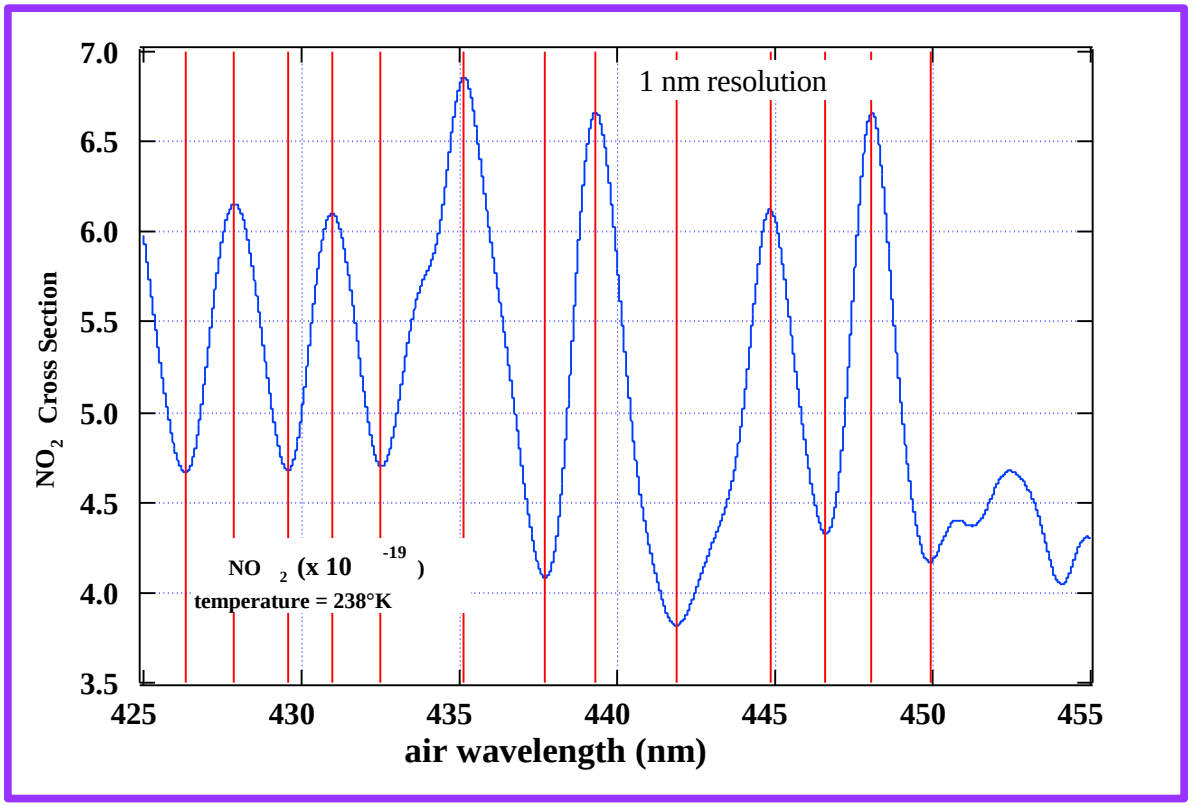
- Hardware procurement and fabrication is underway.
  - Procurement/Fabrication is currently underway for all sub-systems.
    - Detector
    - Telescope
    - Filter/FPA holder
  - Sub-systems integration is expected to begin in late October.

- STAAC Support
  - Instrument manager and systems engineering support is being coordinated by STAAC to assist in integration and evaluation of hardware.
  - Further GSFC AETD/STAAC support will be explored.

Requirements Analysis: NO_2 sensitivity analysis results

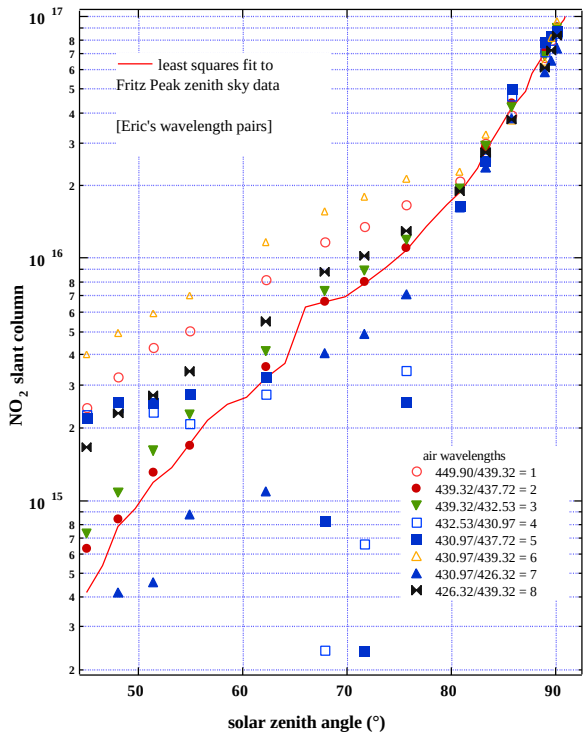
- Goal:
  - Maximize sensitivity and stability of predicted NO_2 retrievals using a finite set of wavelengths.
  - Apply results of analysis to set constraints on instrument properties such as:
    - Filter and optical performance.
    - Throughput (for signal-to-noise ratio)
    - Detector specifications.
- Method
  - I. Pair retrievals using Fritz peak data.
  - II. Multi-spectral retrievals using synthetic data and inputs from GOME.
  - Maximize sensitivity by varying number, position and/or bandwidth of measurement channels.
  - Apply selection criteria.
  - Evaluate constraints on system.

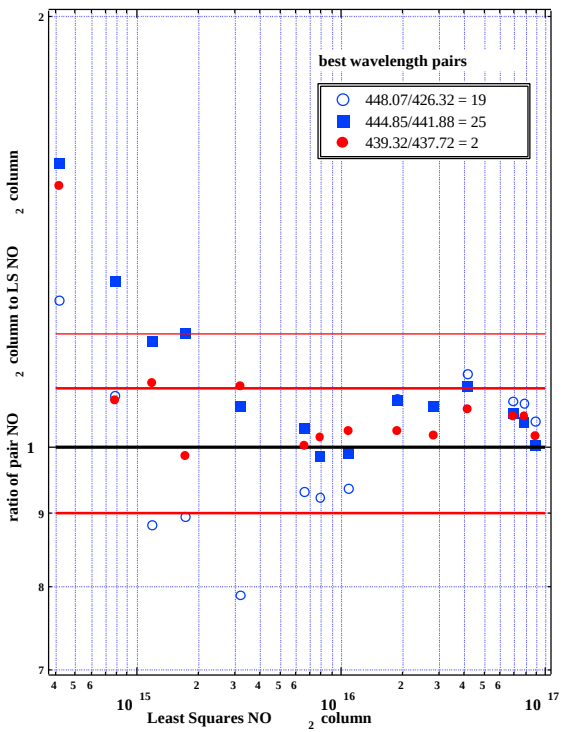
NO2 wavelength selection



1 nm smoothed NO_2 cross section. Measured spectra will be a convolution of this structure with others such as Rayleigh, Ring spectra, O_3, O_4, H_2O, and noise.

Best pair derivation using Fritz peak data

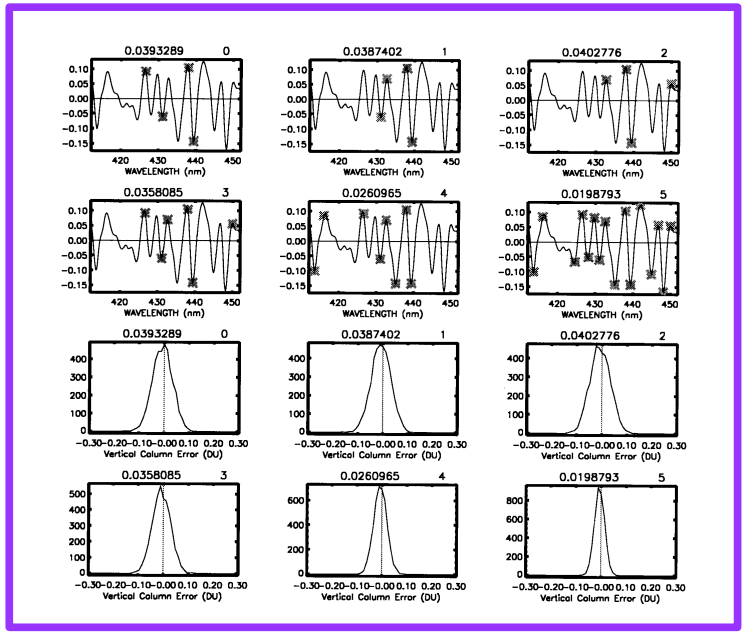


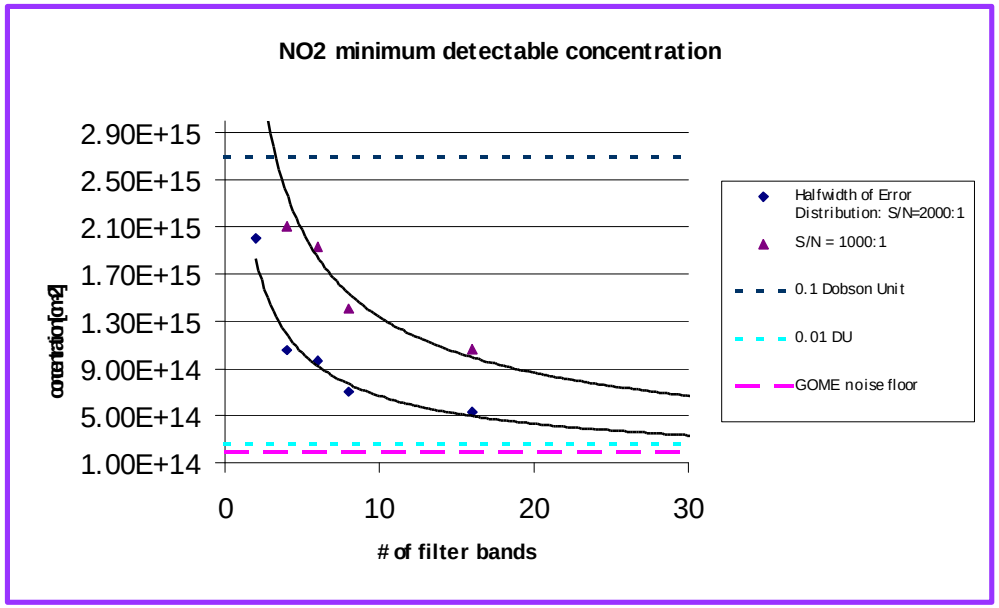


Slant column NO_2 derived by least squares analysis (solid line) with values derived using several pairs of candidate wavelengths. Pair 439.32/437.72 nm tracks multi-wavelength retrieval down to 2e15 cm^{-2}

Best fit pairs +/- 10% error down to 2e15 cm-2 when shifted by +/- 0.1 nm.

Minimum retrievable NO_2 amounts using > 2 channels

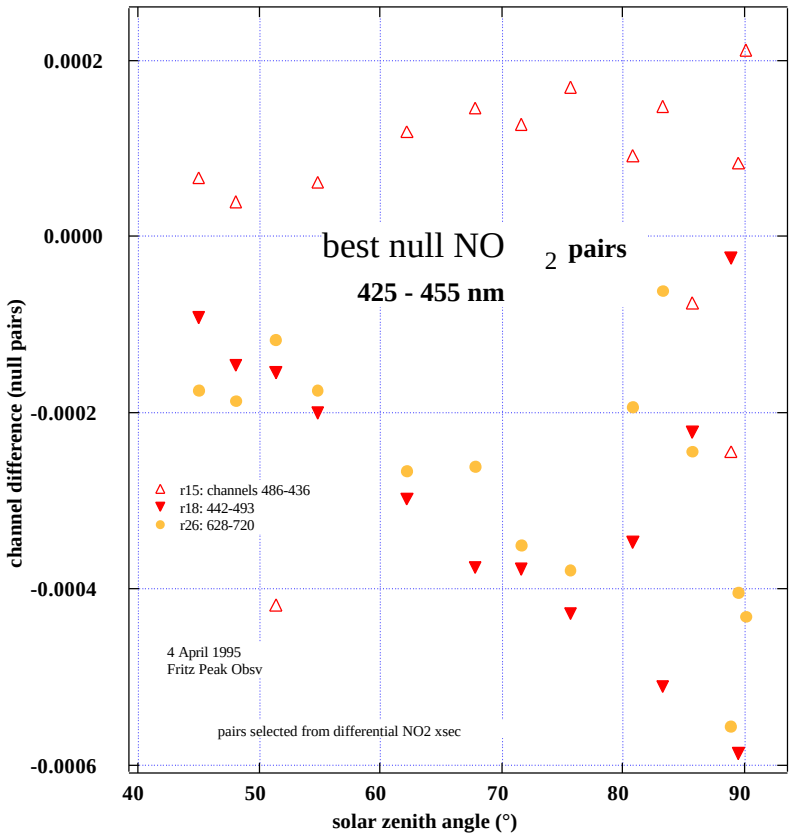




1680 combinations of 4 wavelengths were tested. Best 4,6,8,16 multi-wavelength retrievals selected based on stability to +/- 0.1 nm shifts.

Minimum sensitivity vs. number of filter bands. Retrieval accuracy was not effected by filter band shape. Full DOAS retrieval limited by assumed noise floor (from GOME).

Additional NO2 analysis



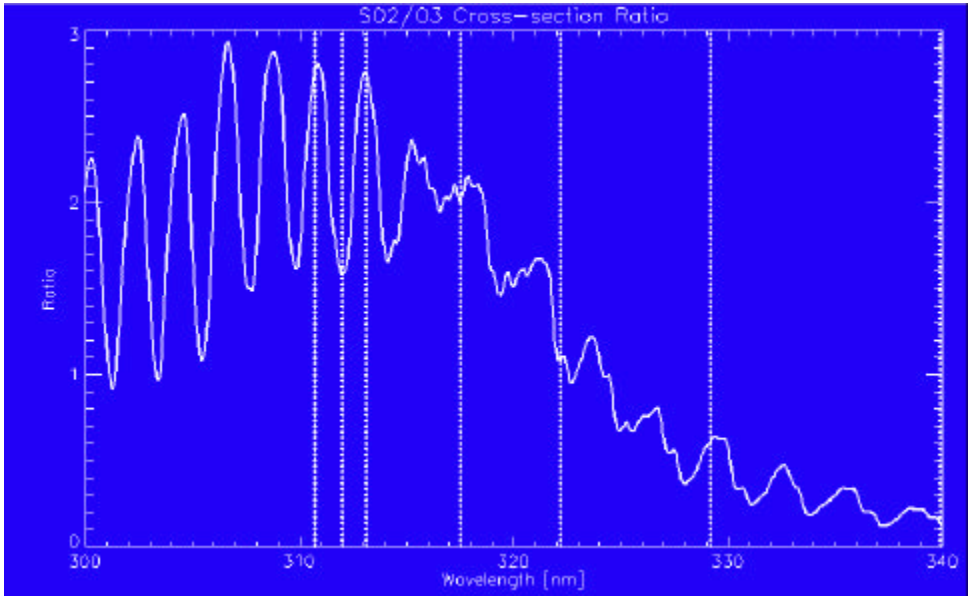
Null pair cross section difference.
423.6/429.6 nm has smallest residual.

Null pair selection was made to allow test of instrumental effects. Retrievals with this pair will yield instrument noise floor.

The effects of using different temperature cross sections was looked at. The net error in retrievals using a temperature variation of 238K - 293K was only +/- 5%

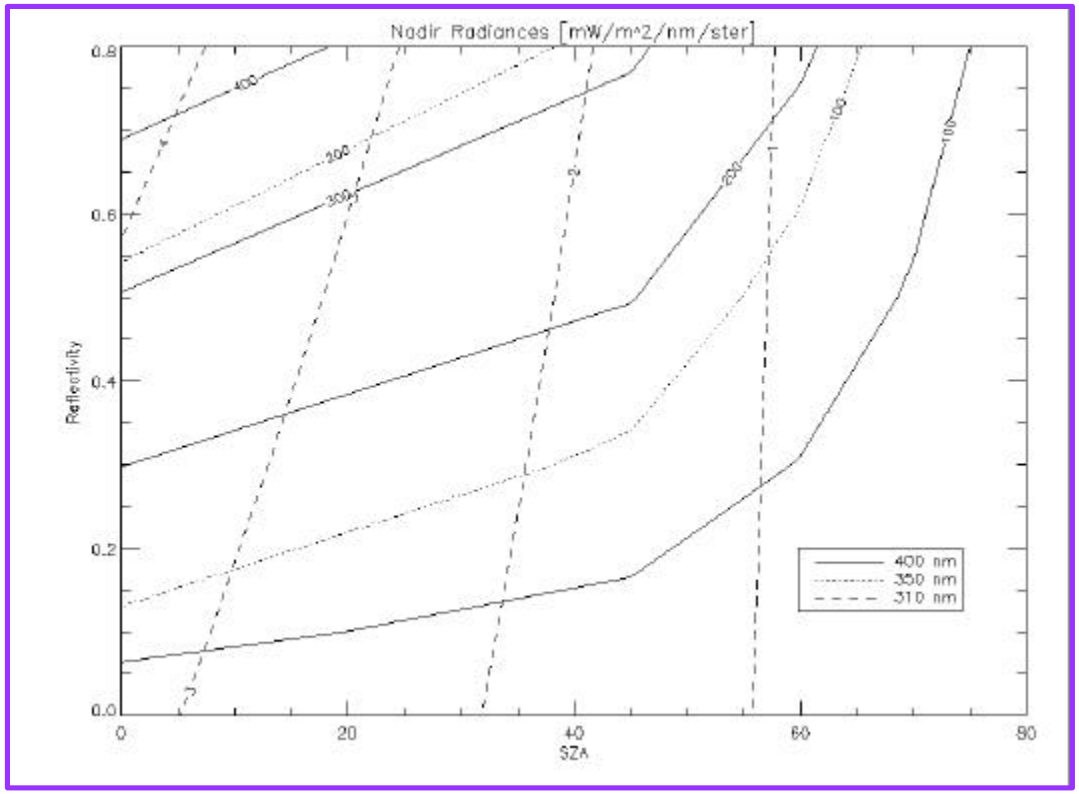
SO_2/O_3 Sensitivities

- Use ratio of SO_2 to O_3 cross sections to determine candidate wavelengths.
- Limited at short wavelength side by Rayleigh scattering and telescope transmission.
- Linear calculations show minimum retrievable concentrations of ~0.5 DU.
- Ozone contamination implies full radiative transfer calculations need to be performed. These will be included in the end-of-phase report.



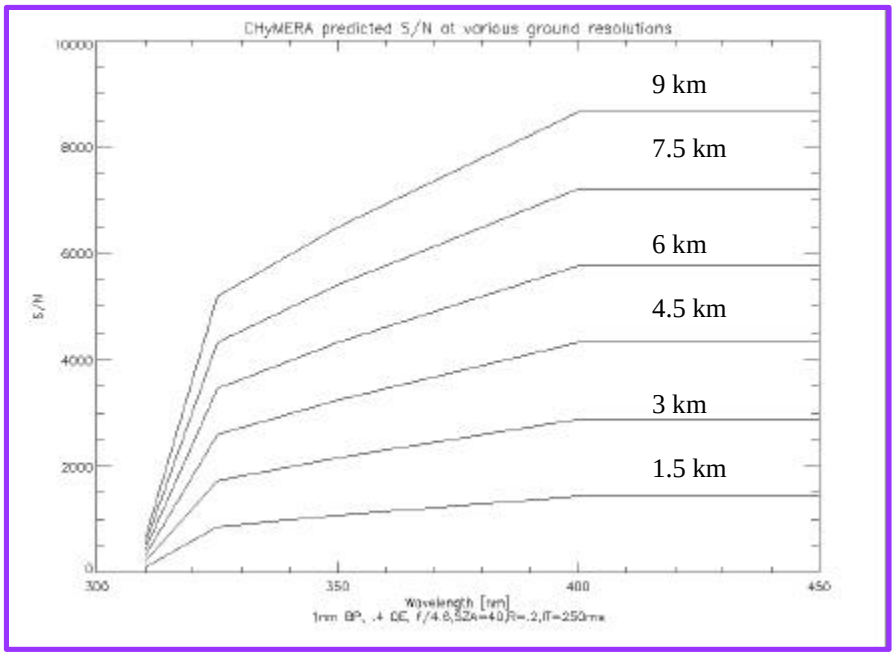
Signal-to-noise ratio calculations

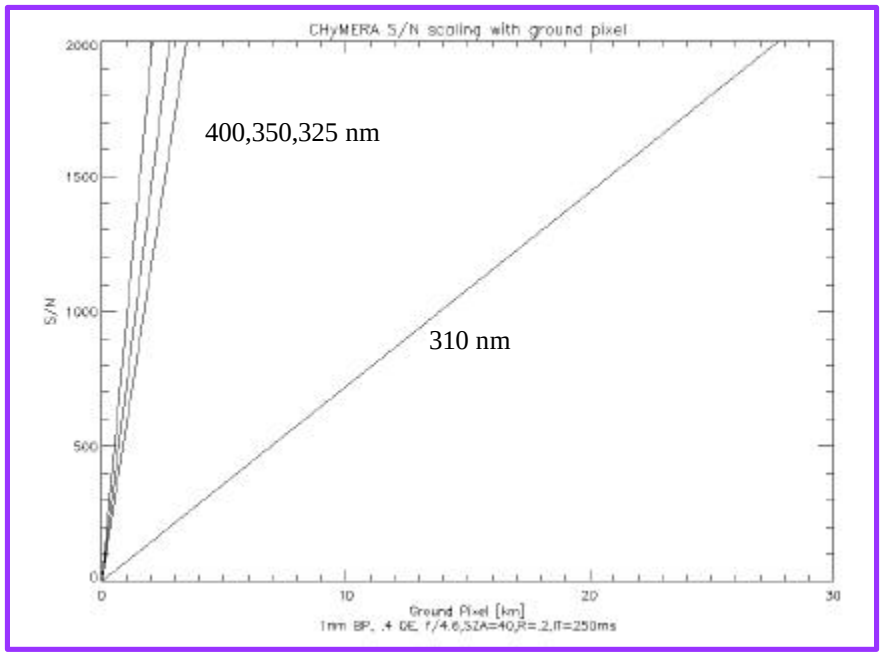
- Sensitivity analysis assumed noise contribution (typical of GOME radiances) equivalent to tau=.0005 or S/N=2000
- Use expected radiances and calculate instrument throughput to estimate signal-to-noise ratio under typical viewing conditions.



Expected Nadir radiances as a function of reflectivity and solar zenith angle

Achievable spatial resolutions





- Expected signal-to-noise and ground pixel resolution of strip filter array using instrument throughput estimate and sample lighting conditions.
- Spatial oversampling = 40
- Signal-to-noise > 2000 achievable on 5km ground scale for NO_2, Ring, and some O_3 wavelengths.
- Signal-to-noise > 1000 achievable on 15 km ground scale for SO_2.

Implications of results of sensitivity analysis

- Final performance will be trade-off between ground sample size and concentration error.

- For S/N of 2000:

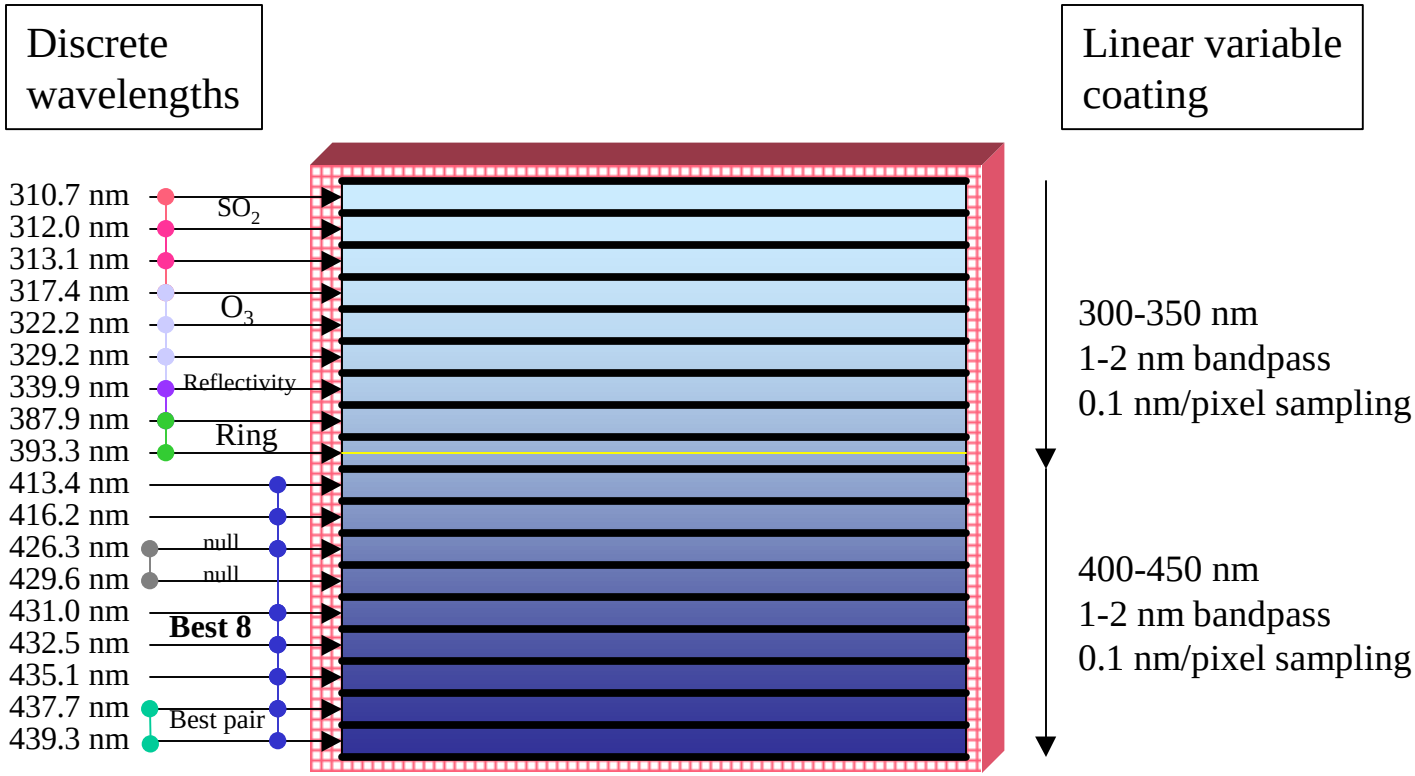
Trace gas	Min. Amount [cm^{-2}]	Resolution
NO_2	8e14	< 5km
SO_2	1.4e15	< 30 km
O_3	1.4e15	<10 km

- The above results were used to constrain the instrument design, particularly with respect to the specifications of the filter performance, telescope performance, and detector performance.

Filter Arrays

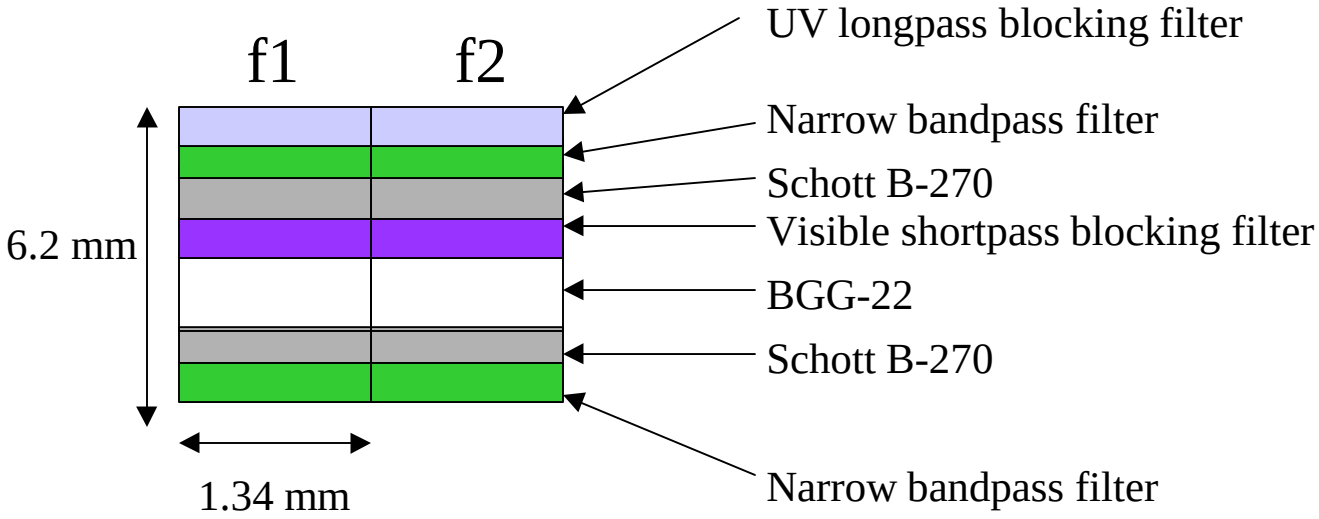
- Two approaches are under investigation
  - Requirements analysis defined filter specifications:
    - +/- 0.1 nm wavelength accuracy
    - $< 10^{-7}$ out-of-band rejection
    - transmission > 40%
    - 1 nm bandwidth
  - Strip filter method
    - More fully developed and tested technology.
    - Spatial oversampling increases signal-to-noise ratio.
    - Internal scattering could be an issue.
  - Linear variable filter
    - Able to easily check for wavelength shifts.
    - Wavelength oversampling increases signal-to-noise ratio.
    - Vignetting and internal scattering not an issue.
    - Not sure that out-of-band and bandpass requirements can be met.

Strip filter/Linear variable filter layout

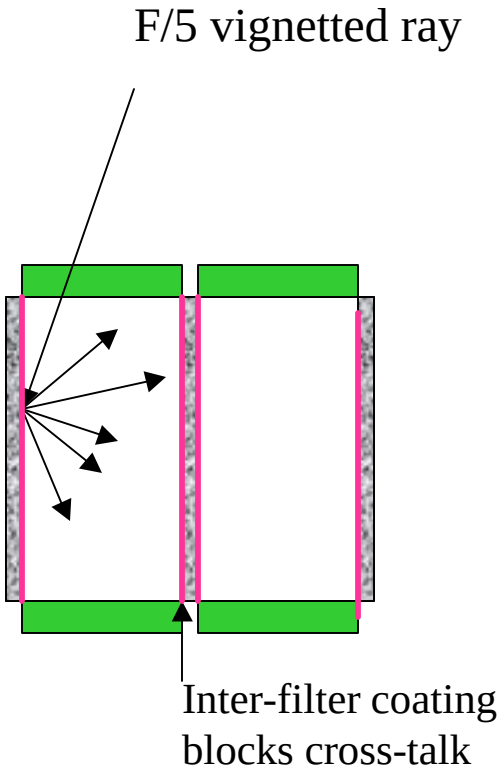


Geometry for 18 filters:
1.34 mm x 33 mm filter strips
(56 x 1024 pixels per filter)

Example of NO2 wavelength filter cross section



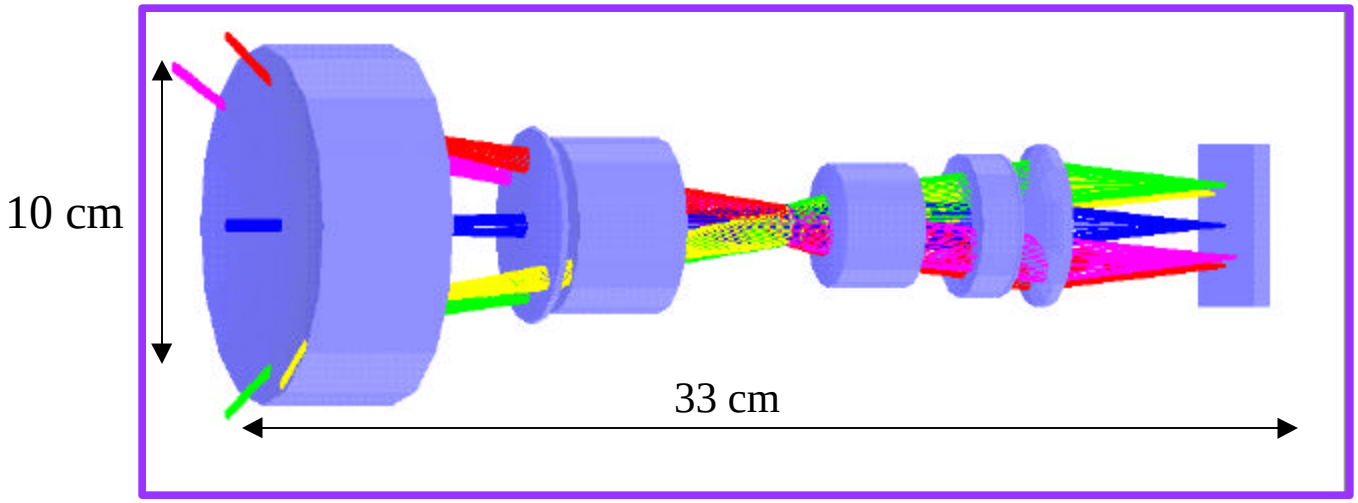
Front and backside bandpass coating for internal reflection reduction. Diffuse edges disperse rays which are then blocked by backside coating due to angle of incidence mismatch.

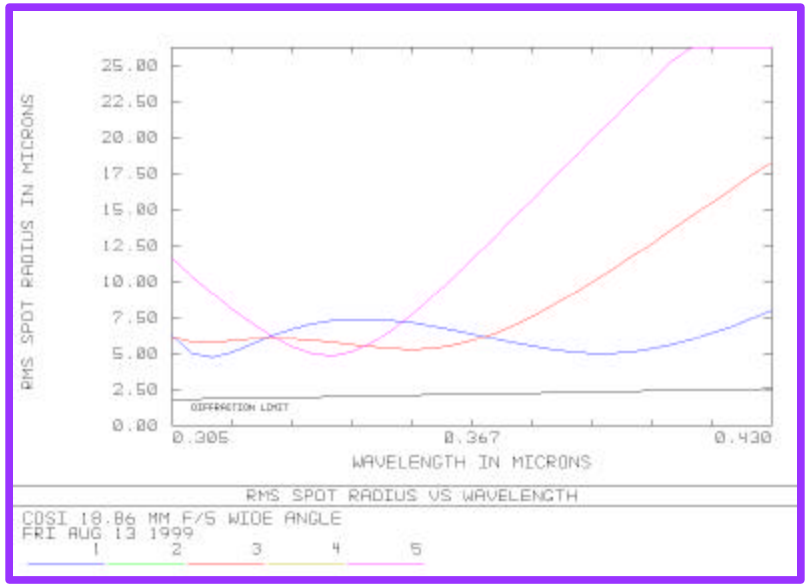


Optics

- Two approaches investigated
  - Requirements analysis in addition to providing a wide-swath mapping capability defined the telescope specifications:
    - Spot size < 25 um over spectral range 300-450 nm and field of 63 degrees.
    - transmission > 40%
    - Telecentric, back-focal length > 50 mm
  - Reflective design
    - Advantages
      - Easier to control ghosts/stray light.
      - Possibly more stable vs. multi-lens system.
      - Magnification varies with wavelength.
    - Disadvantages
      - Need at least one, probably two lenses to get adequate spot sizes.
      - Tilted focal plane is difficult to handle.
      - Bulky design.
  - Refractive desgin
    - Advantages
      - Excellent image quality.
      - Compact.
      - Able to correct for axial color with proper choice of glasses.
    - Disadvantages
      - Multiple ghosts, needs close attention to AR coatings.

Refractive Telescope Design

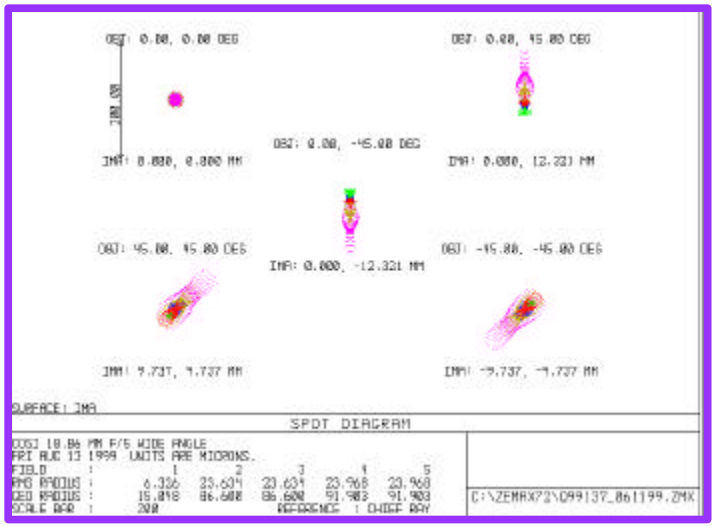


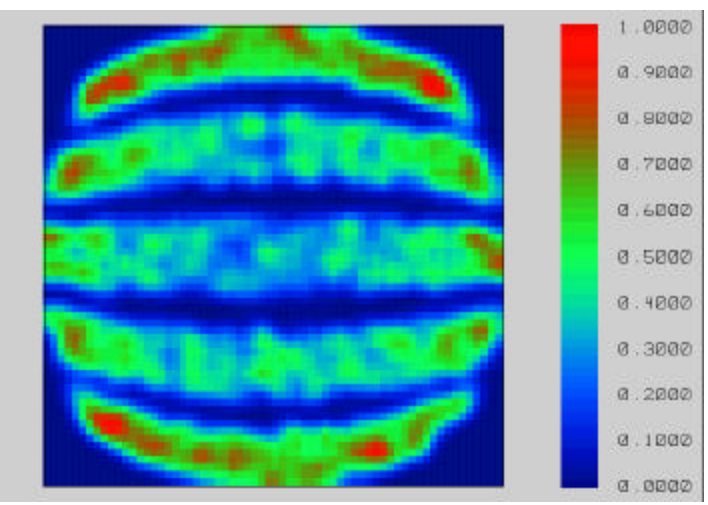


- 90 degree square field.
- Spot sizes < 1 pixel for all wavelengths over full array.
- Axial color shift minimized.
- 0.5% reflection per surface.
- F/5 system.

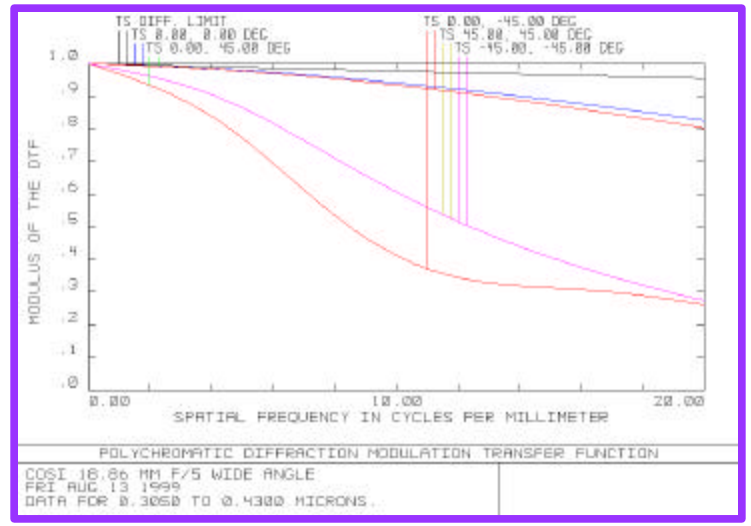
Telescope Details

Different color images co-aligned





Modulation transfer function



<u>Simulated grid image at detector</u>

- Field distortion is apparent.
- Distortion will degrade resolution by ~factor of 2 at corners, not significant when binning pixels.

Detector System

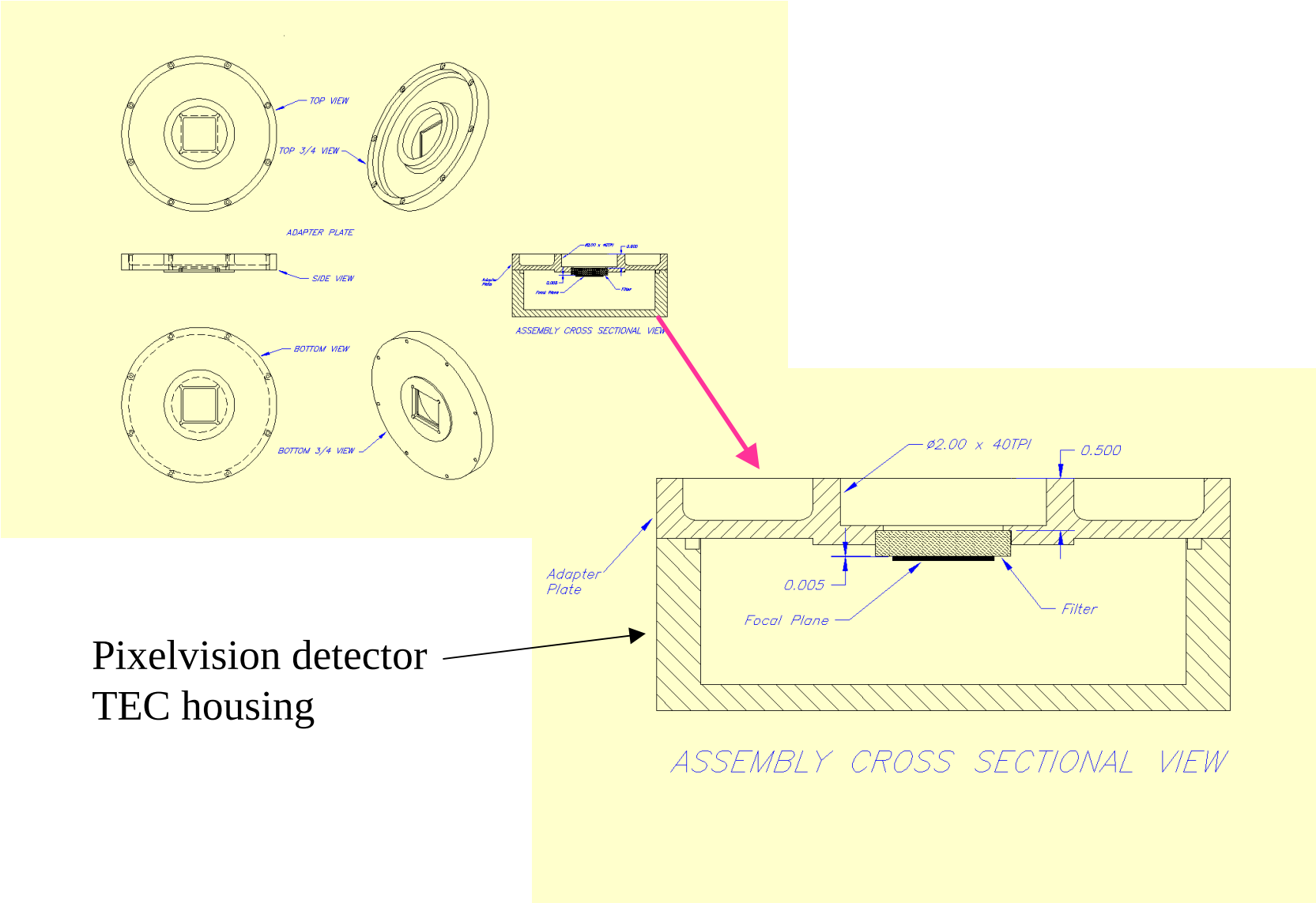
- Originally planned to have CODE 553 build custom electronics for donated Hubble ACS flight spare. Time scale for development of the read-out electronics for this array was found to be 7-8 months.
- Commercial system will be used to evaluate technique. PixelVision quad-readout system will be modified to accept filter array mount.
- Requirements;
  - 1024x1024 pixel format, unsealed detector.
  - Capable of 2 Hz frame rate.
  - non-linearity < 1%.
  - QE > 25%, 300-450 nm

SpectraVideo Microscopy And Imagery Typical Camera Specifications

Model #	Imaging Format	Architecture (Full Frame)	Pixel Size	CCD Manufacturer	Maximum Frame Rate	Full Well (Binned)	Full Well (Unbinned)	Dark Current (e-/pix/sec @ -45° C absolute)	Noise (rms @ 50 kpix/sec)
SV40CAF	4096 x 4096	Front-Illuminated	15µm x 15µm	Loral	0.5 fps	325 ke-	80 ke-	1	4-9
SV20CCF	2048 x 2048	Front-Illuminated	15µm x 15µm	Loral	0.2 fps	325 ke-	160 ke-	1	9-12
SV16CAJ	1600 x 1600	Front-Illuminated	18µm x 18µm	SITe	0.36 fps	600 ke-	85 ke-	1	4-9
SV10CDJ	1024 x 1024	Back/Front-Illuminated	24µm x 24µm	SITe	0.6 fps (2.4 fps w/ 4 output)	900 ke-	325 ke-	1	4-9
SV512AJ	512 x 512	Back/Front-Illuminated	24µm x 24µm	SITe	3 fps	900 ke-	325 ke-	1	4-9
SV512AH	512 x 512	Front-Illuminated	19µm x 19µm	Thomson	3 fps	600 ke-	210 ke-	0.8	5

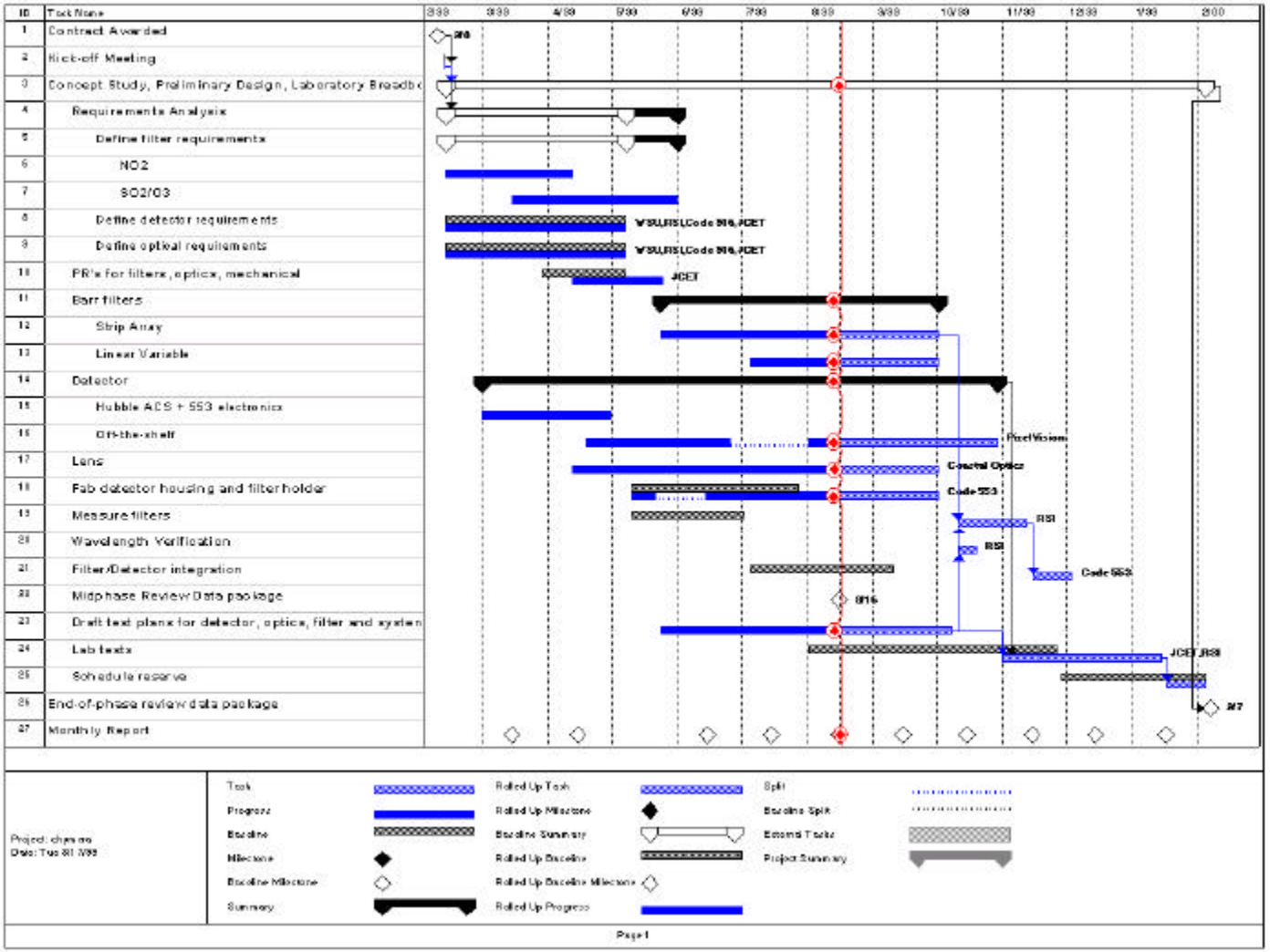
Camera Characteristic	Detail	Specification	Units
Digitization	(-)	16	bits
Maximum Digitization Rate	(-)	1 M	pix/sec
System Conversion Gain (software selectable)	typical LOW/HIGH	5/10	electrons/DN
Non-linearity	typical	<1 %	deviation from mean
Binning and ROI	row and column	YES	(-)
Shutter Speed	minimum	15 (25mm) / 50 (35mm)	msec
Cooling Capacity	2-stage TE Vacuum Module	-45 to –55	° C from ambient
	3-stage TE O-ring Dewar	-65	° C from ambient
	Cryogenic Cooling	Contact Factory	(-)
Image Acquisition and Processing Software	PixelView	Provided with Camera	Windows 95/98 or NT
Image Acquisition Board	PCI Bus	parallel (standard) fiber optic(optional)	(-)
Triggering	Software Selectable	Internal, External Trigger, External Gate and Software Trigger	TTL
Row Shift Period	typical	24-60	µsec
Computer System	recommended	Pentium 233 MHz, 32 MBytes RAM, w/ Windows 95/98 or NT	(-)

Filter holder design

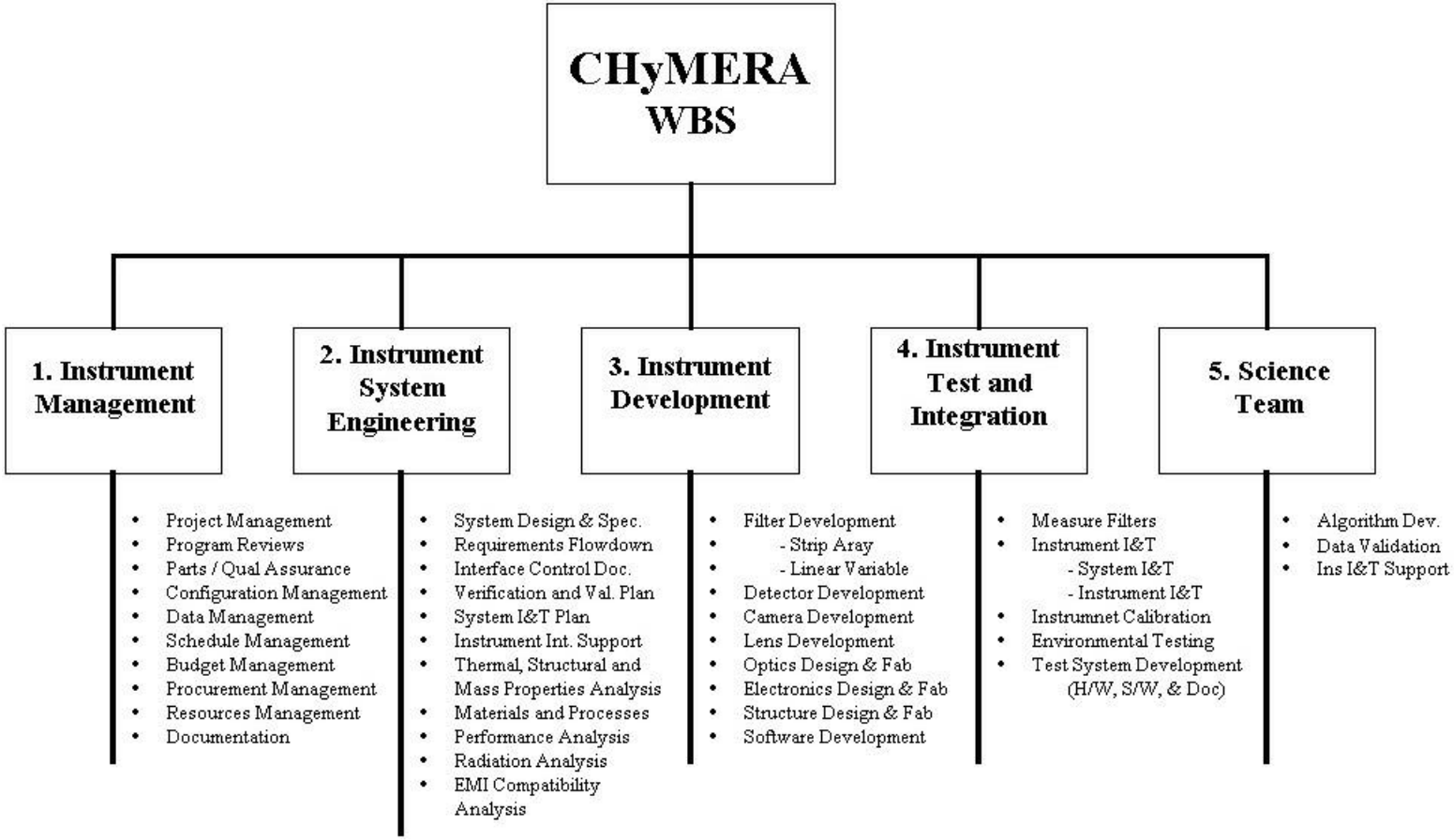


Pixelvision detector
TEC housing

Project Schedule



Work Breakdown Structure



CHyMERA Work Breakdown Structure (WBS)