MAESTRO

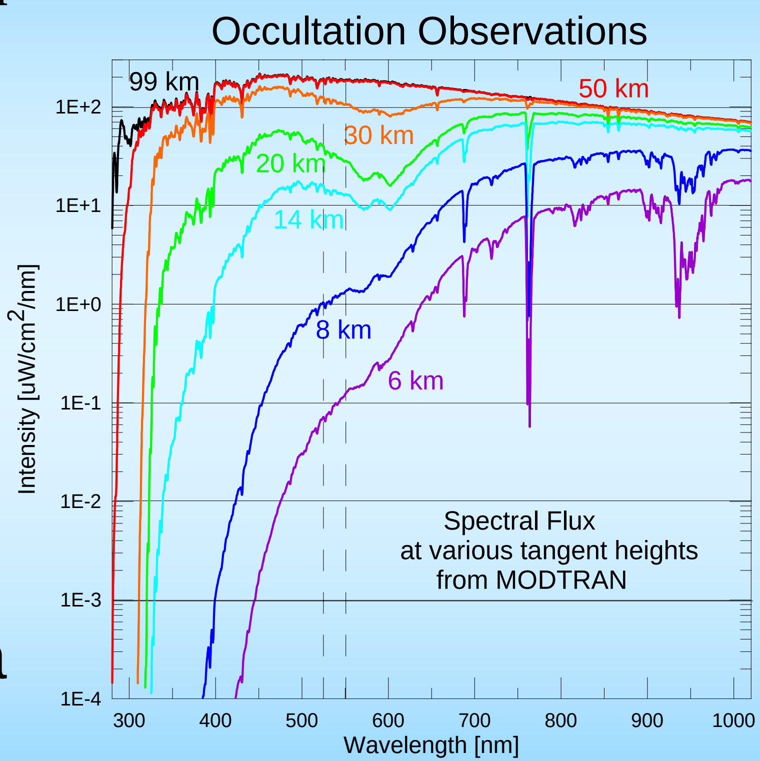
A C E

Measurements of **A**erosol **E**xtinction in the **S**tratosphere and **T**roposphere **R**etrieved by **O**cculation

The MAESTRO Instrument will fly on SciSat I: the Atmospheric Chemistry Experiment (ACE)

Tom McElroy
Senior Research Scientist
Meteorological Service of Canada

Environment Canada



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Environment Canada Environnement Canada

University of Toronto

EMS Technologies

Topics for Today

- Introduction
- The Team…
- The MAESTRO Instrument
- Probable Products
- Analysis Approach
- Instrument PerformanceValidation
- MAESTRO Status

The Instrument Team…

- Meteorological Service of Canada
  - Experimental Studies Division
- University of Toronto
  - Atmospheric Physics Group
- EMS Technologies
  - Industrial Partner
- Canadian Space Agency
  - (Instrument Funding)

Rogues Gallery

- James Drummond (U of T)
- Ben Quine (U of T)
- Clive Midwinter (MSC)
- David Barton (U of T)
- Robert Hall (MSC)
- Aaron Ullberg (MSC)
- Caroline Nowlan (U of T)
- Denis Dufour (U of T)

(and others)

Spectrometer Requirements

- Occultation and Backscatter Observations
- ~1 km Vertical Resolution [0.02 degrees]
- ~80 km Backscatter Resolution [7 deg.]
- Wide Spectral Coverage [285-1030 nm]
- Moderate Resolution [~1-3 nm]
- High Signal-to-Noise Ratio [>3000:1]
- Large Dynamic Range [>1.0E5]
- Accurate Stray Light Model

'Operational' Science

- O_3 and NO_2 Profile Measurements
- Aerosol Transmission
- Measurements Down to <10 km

‘Scientific’ Data Products

-(p, T), O_2 (A, B, ☎), O_4

-SO_2, H_2O, BrO, OClO

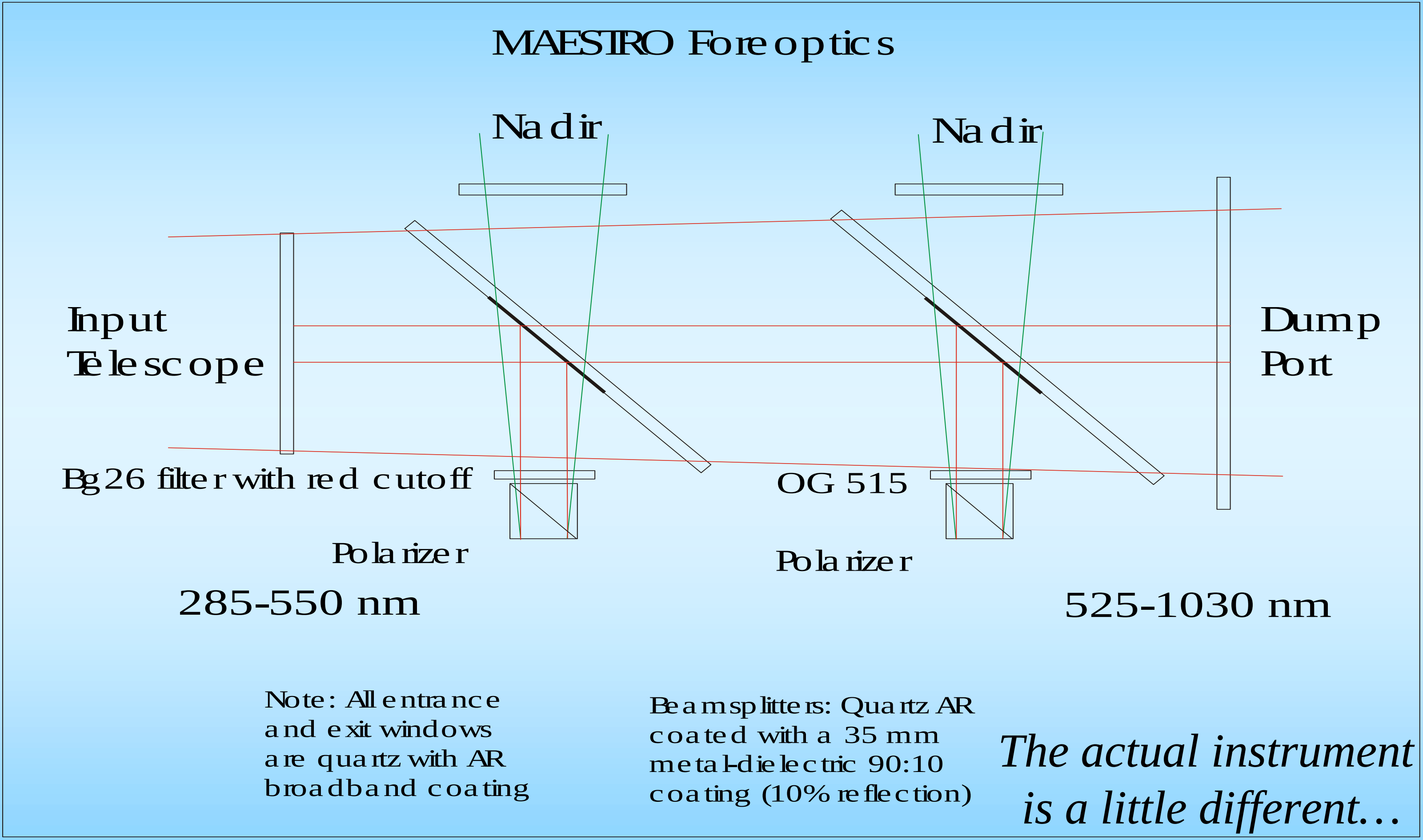
-Perhaps Possible: ClO at 40 km

-Backscatter Observations

-Aerosol Physical Properties

-Measurements Down to 5 or 6 km

Fore-optics Concept



The actual instrument is a little different…

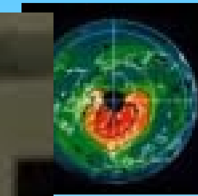
MAESTRO at U. of T. ...

MAESTRO in the Instrument Calibration Facility at University Of Toronto

Photo courtesy of U. Toronto

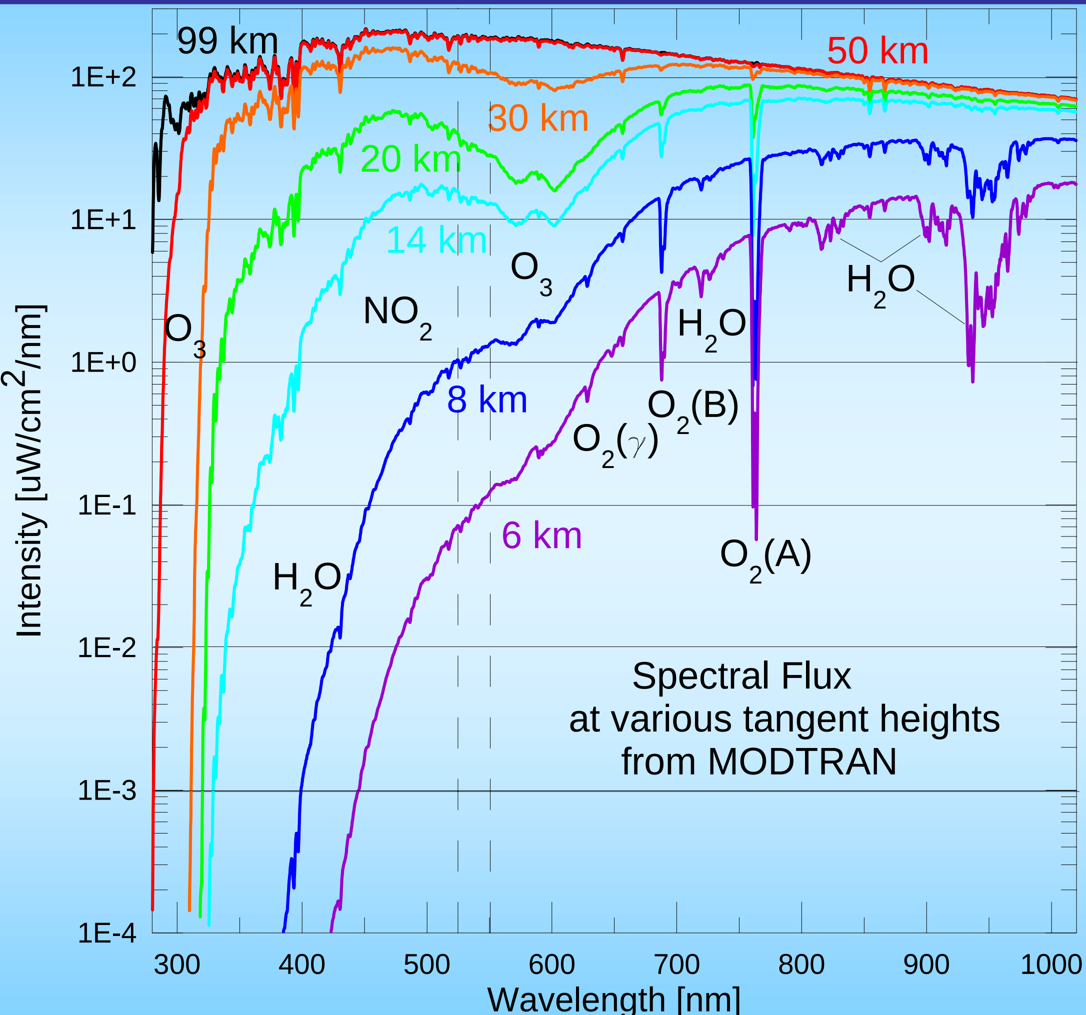
MAESTRO

SciSat-1 Rear View



What Does One See?

Occultation Observations



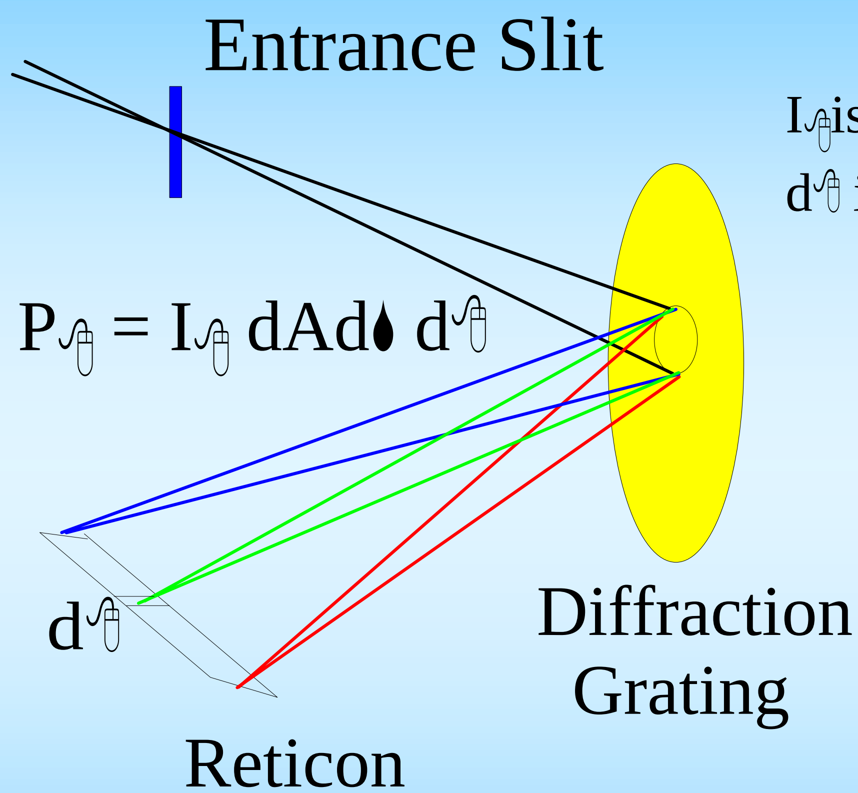
Dashed Lines Indicate Region of Overlap Between two Spectrophotometers

Serious Issues…

- Slit Function
- Sensitivity, Etalonning & Pixel-to-pixel Gain
- Dynamic Range, Dark count & Noise Level
- Stray Light, Linearity & Thermal drift (analog)
- Resolution, Free Spectral Range
- Wavelength Assignment
- Altitude Assignment

… for occultation measurements

MAESTRO Spectrometers (2)



$P_\lambda = I_\lambda \, dA \, d\Omega \, d\lambda$

I_λ is solar intensity

$d\lambda$ is wavelength resolution

$dA = l \bullet w$
where l = slit length
and w = slit width

$d\lambda = D \bullet w$
where D is the dispersion
and w is the slit width

EG&G Reticon Detector

- Commercial detector
- Used by ESA's GOME(2) & SCIA
- Large dynamic range
- High resistance to non-linearity
- Low blooming
- Randomly addressable
- UV-enhanced Si photodiodes
- Electrometer amplifier
- 16 bit A/D input
- Controlled by soft-programmable
    FPGA (XILINX)

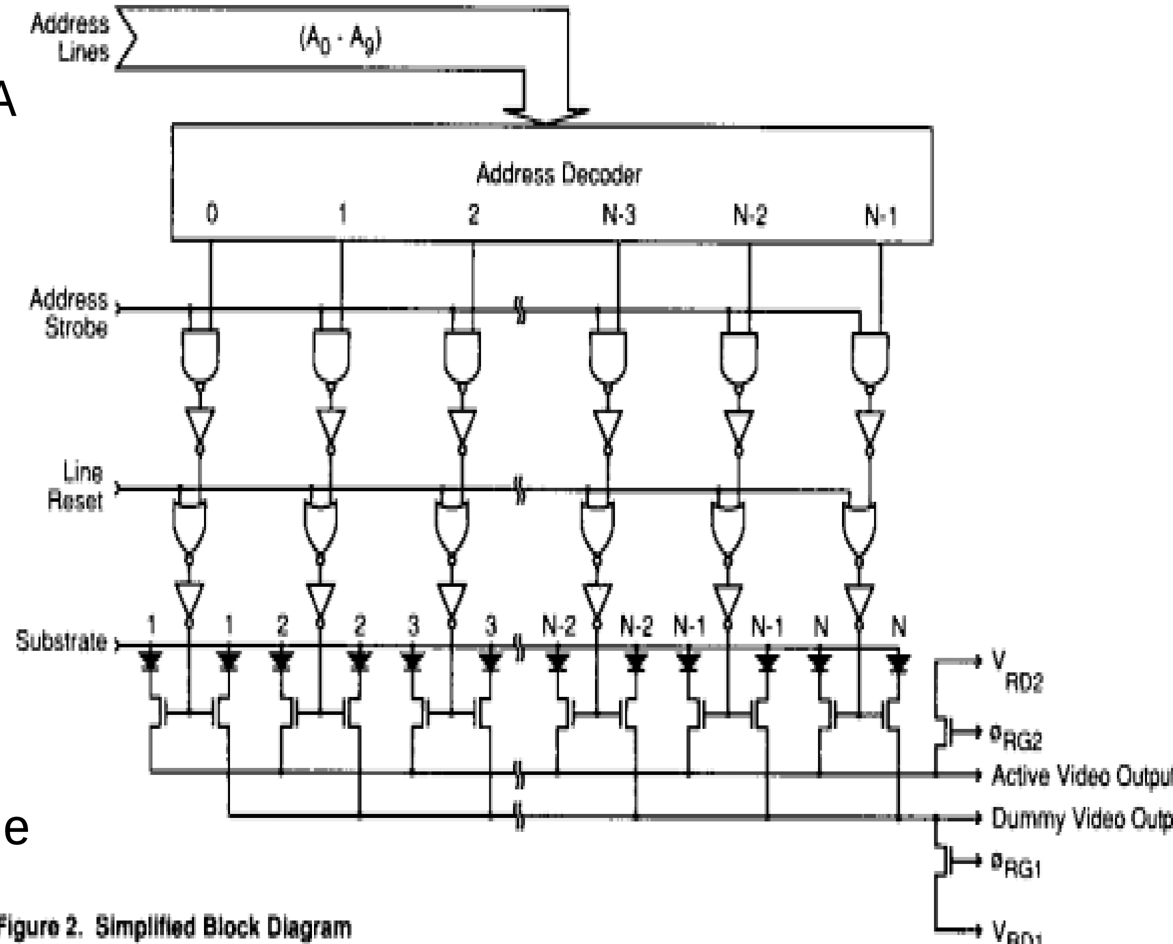
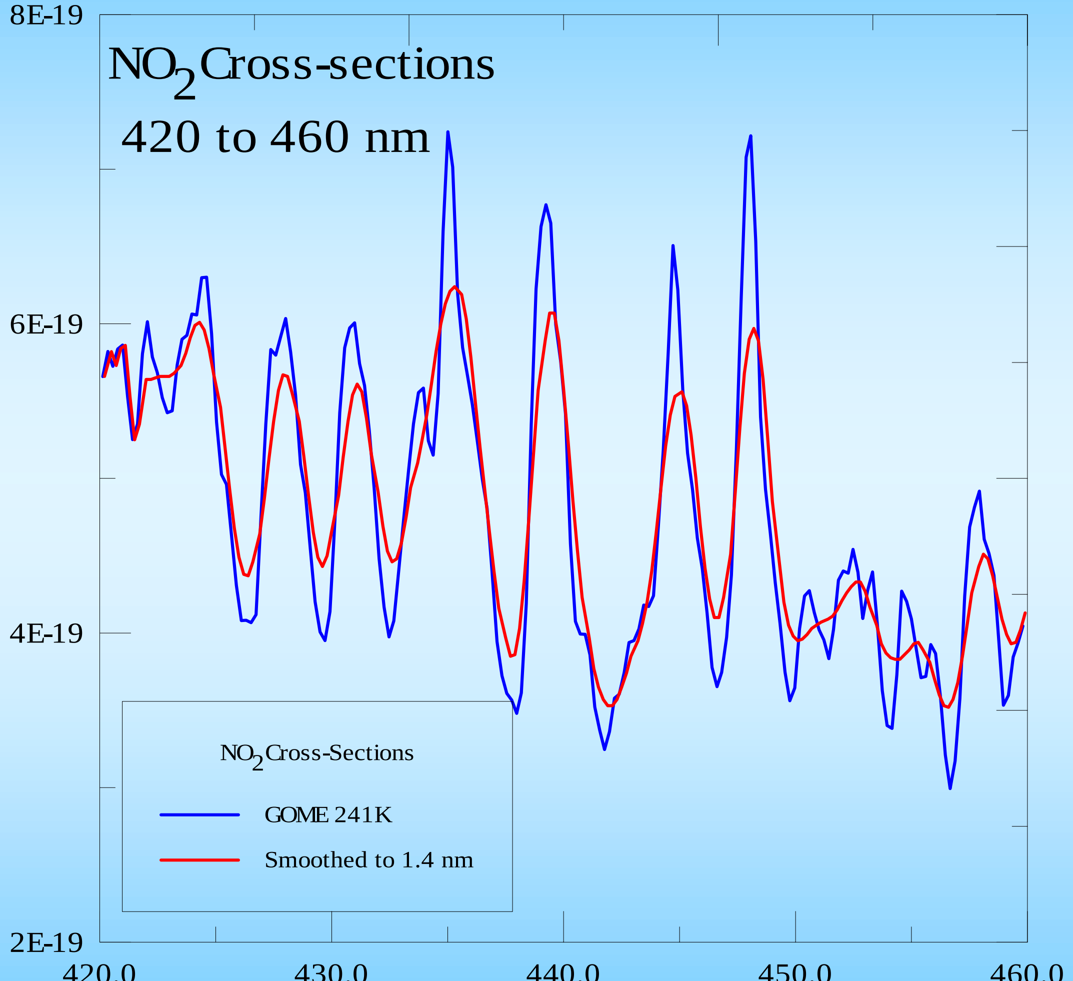


Figure 2. Simplified Block Diagram

Peculiar Features

- Sun scanning at high-sun
- Wavelength scanning
- Internal linearity and video leakage test
- Dual backscatter and occultation mode
- Fast detector readout (~15 μs per pixel)

Nitrogen Dioxide



GOME NO_2 Cross-sections

‘Effective’ Optical Depth

$$\tau_{spt} = \log(S_{spt}) - \log(S^0_{sp})$$

where S_{spt} is the spectrometer signal

$$S_{spt} == S_{spt} (\mu_{ch}, \theta_{ref}, a_{ih}, \text{shift, stretch, dark, stray\_light})$$

s	spectrometer number (UV, Vis)
p	pixel number (wavelength)
t	solar angle [observation] number (θ_t)
i	aerosol parameters (~4)
μ_{ch}	mixing ratio of constituent c at altitude h
θ_{ref}	correction to nominal solar zenith angle
a_{ih}	3 aerosol coefficients plus peak wavelength (=4)

Retrieval

$\chi^2 = (\tau^d_{spt} - \tau^m_{spt})$ ☞$^{-1}_{sptqrv}$ $(\tau^d_{qrv} - \tau^m_{qrv})$

Is minimized for:

$\frac{💣\chi^2}{💣w} = 2\,(\tau^d_{spt} - \tau^m_{spt})$ ☞$^{-1}_{sltqrv}$ $\frac{💣\tau^m_{qrv}}{💣w}$ $(== 0)$

where w represents any one of the elements of μ_{ch}, θ_{ref}, a_{ih}, shift or stretch.

If the differential can be calculated - the mimization can be done. If it is done analytically – it is fast.

Complications

- Quadrant sensor must be modelled to account for refractive ‘spreading’ as a function of wavelength
- High-sun spectra must be oversampled to correct for wavelength shifts
- Atmospheric model will have greater vertical resolution than 1 km (~100 m)
- Account for finite ILS and FOV effects
- Worried about cloud effects [pointing system]

The Way Forward

- The global retrieval (fit all spectra with vertical distribution) will be used

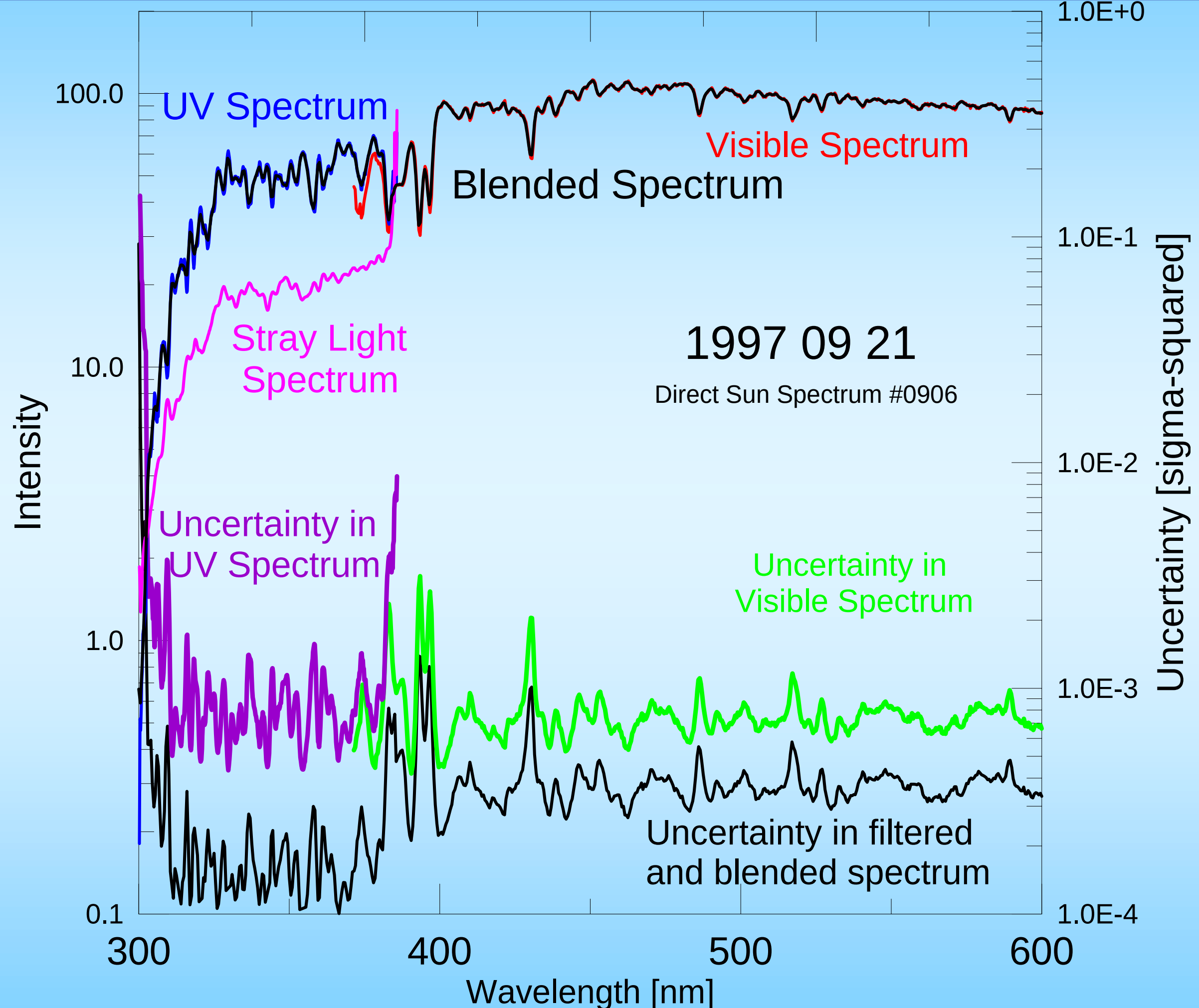
  (with additional constraints)
- We have a 1.4 GHz machine now with a Gbyte of memory (800 x 800 matrix plus 20,000 x 10 x 50 cross-section vectors)
- A better aerosol approach will be included later
- We are writing code for this now
- Can reduce the requirements if need be

Heritage

- Current spectral fitting code (CPFM) does simultaneous shift, stretch, constituent and offsets (both log and linear) using χ^2 minimization
- MANTRA retieval has atmospheric structure and refractive ray tracing code

  (being transported to the MAESTRO retrieval code)
- CPFM instrument model with detector and etalloning corrections – MAESTRO model coming along
- Process control via the database software (Waterloo)

Sample Spectrum (CPFM)



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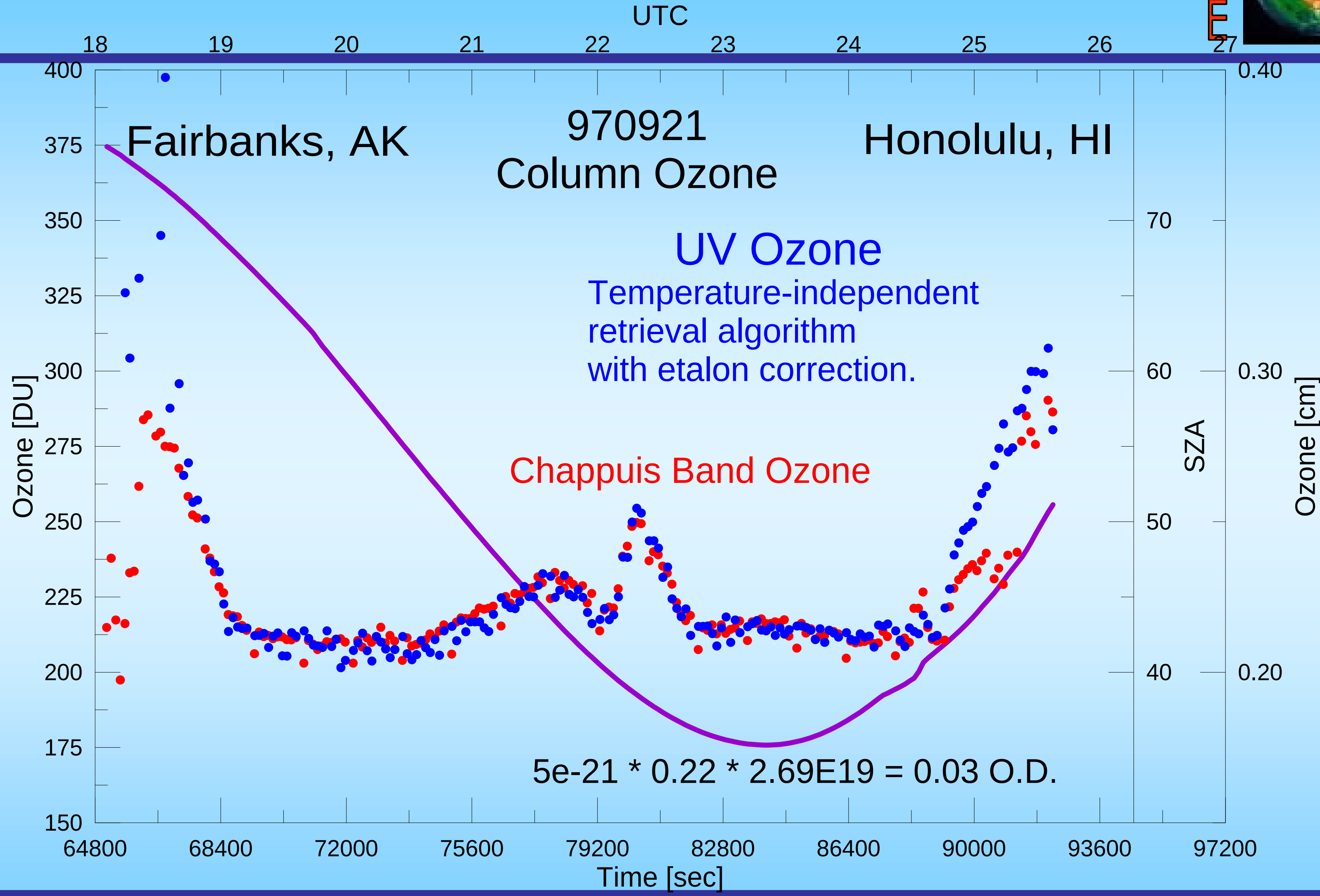
POLARIS Ozone



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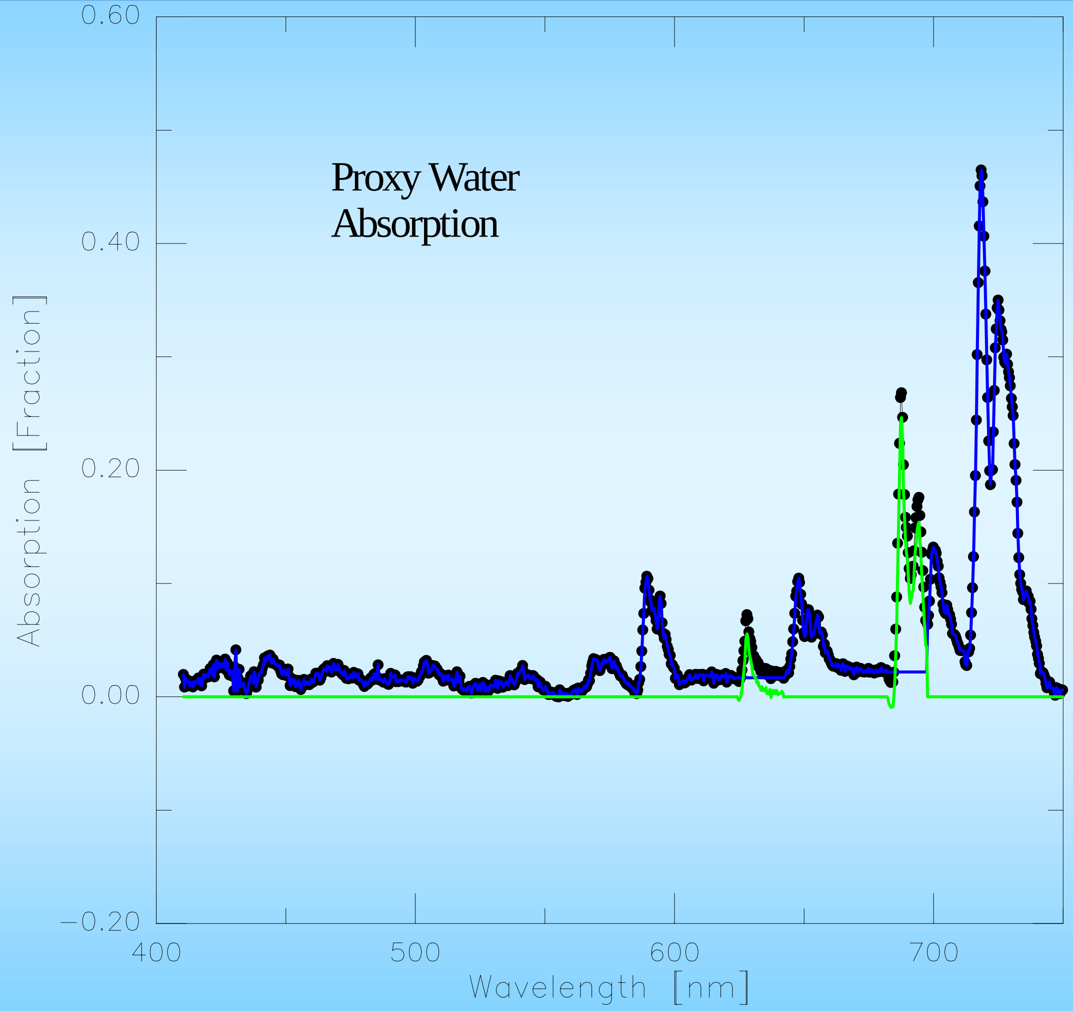
Below the Trop

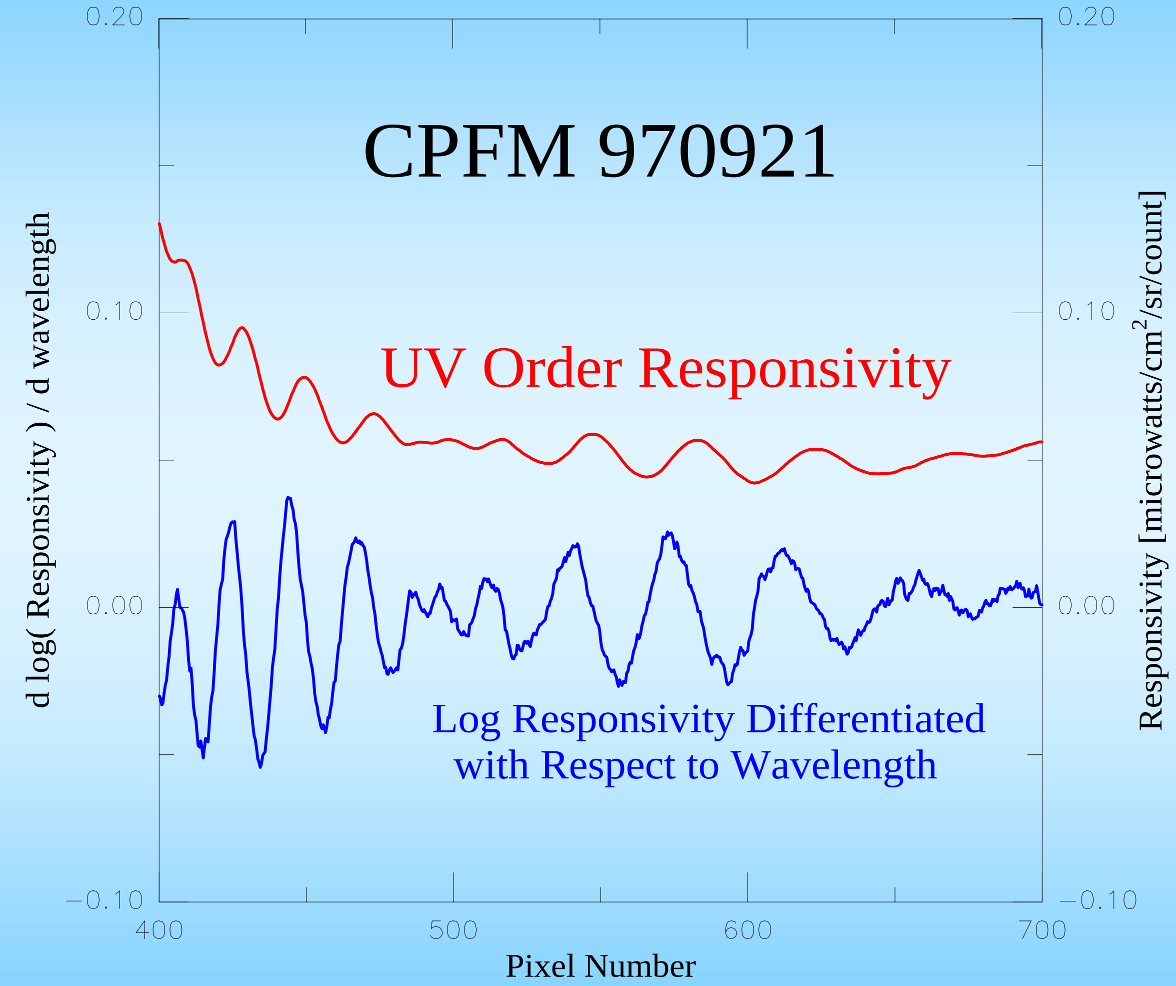
- Clouds
- Large Optical Depths
- Large O_2 Optical Depth
- Pointing Issues
- Water Vapour!!
- Declining Ozone Amount
- Model results suggest we can get NO_2 slant column to 10% in the troposphere (No cloud!)

Water Absorption

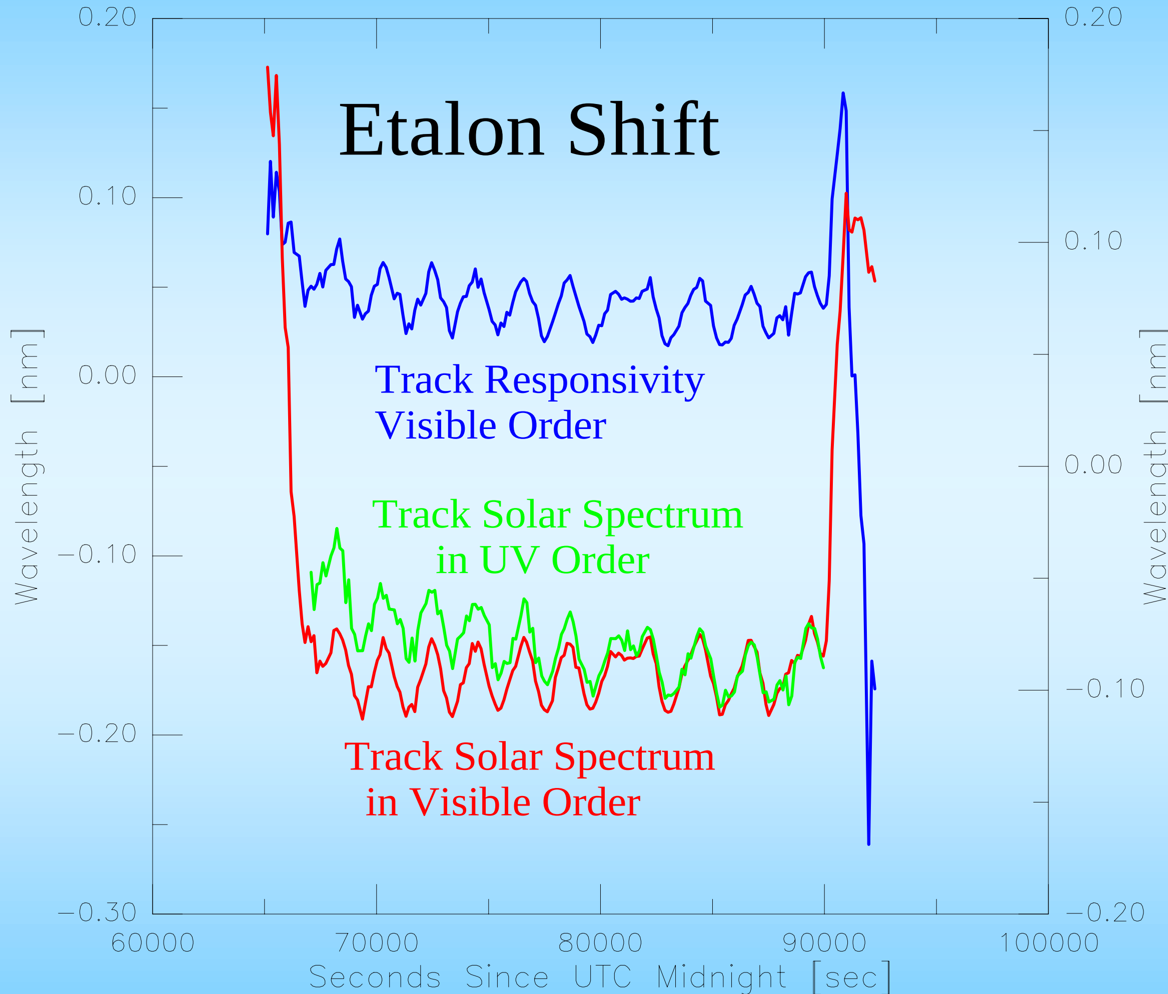


Mean difference between spectra in affected area and clear region.

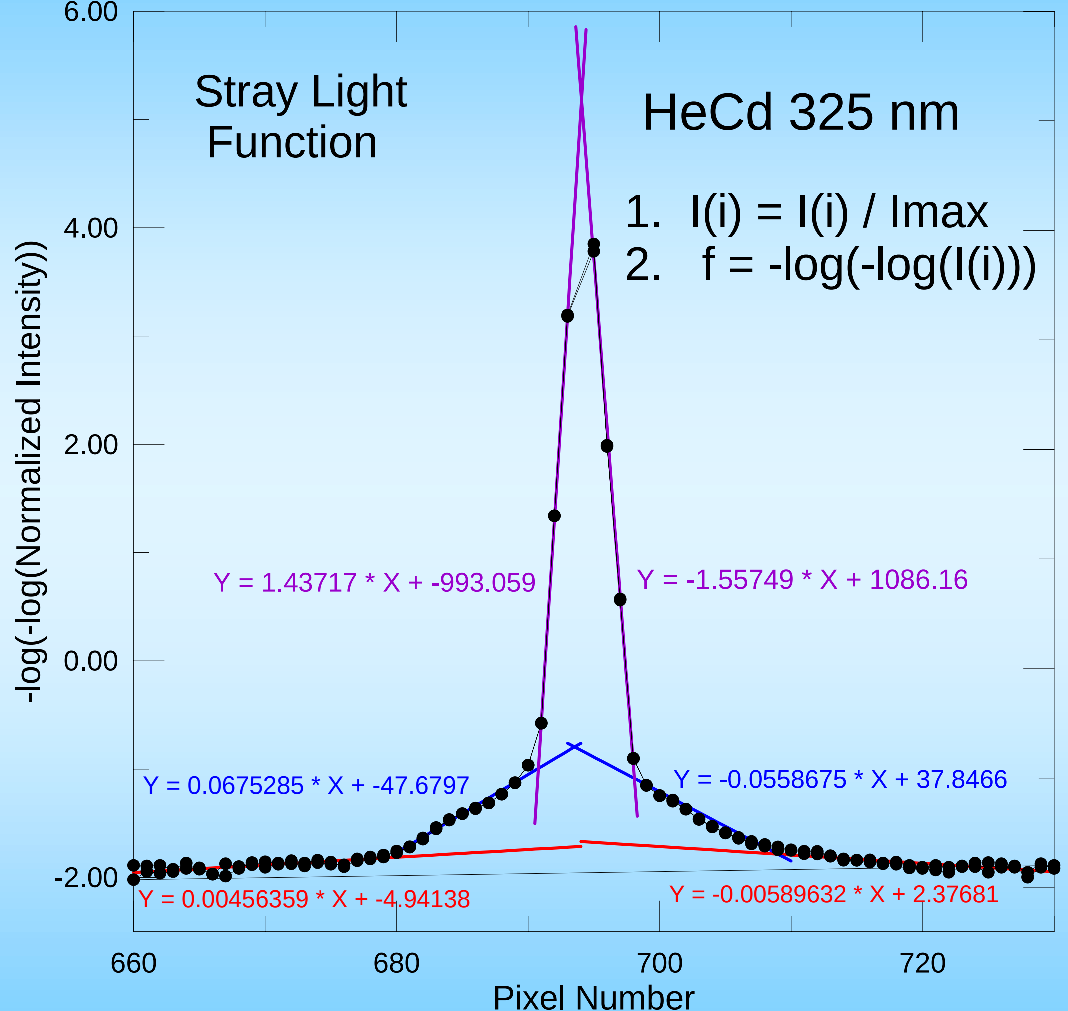
UV Responsivity



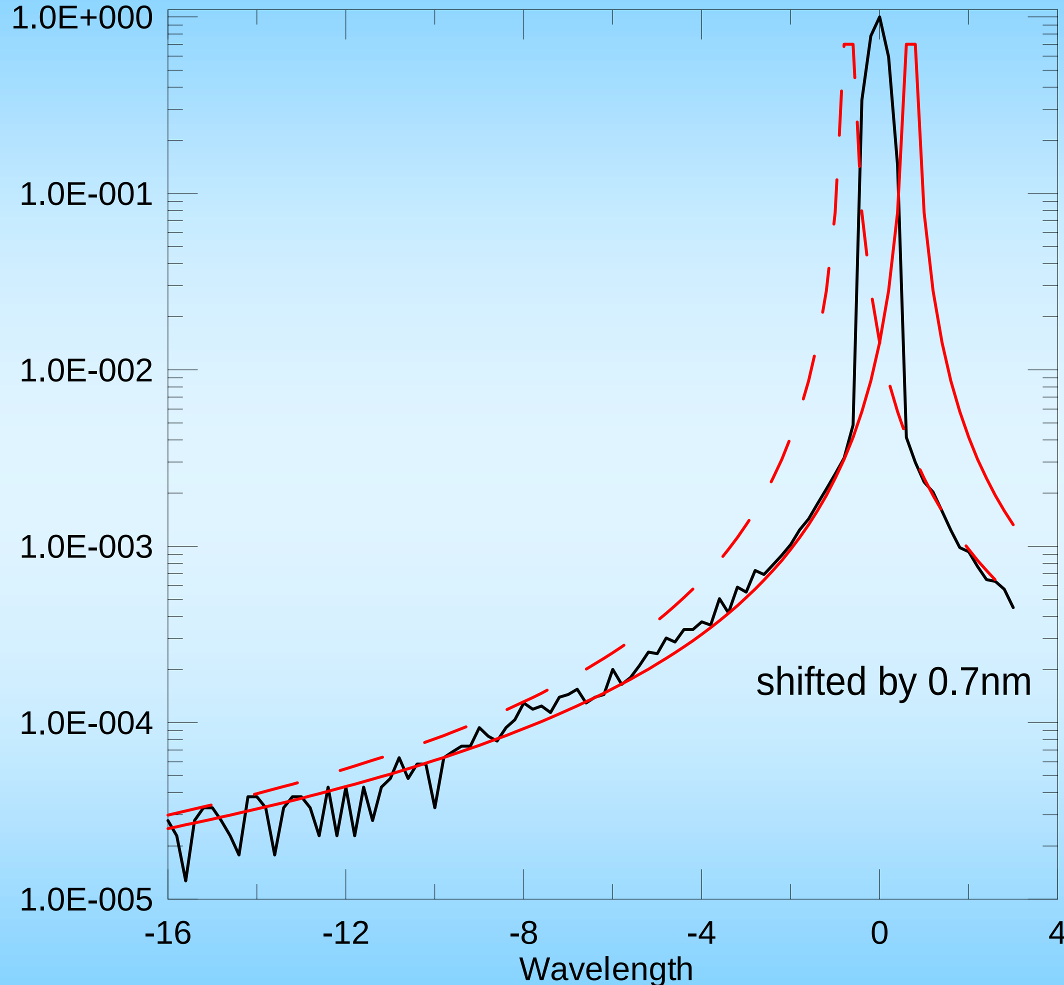
Etalon Shift



CPFM Stray Light Function

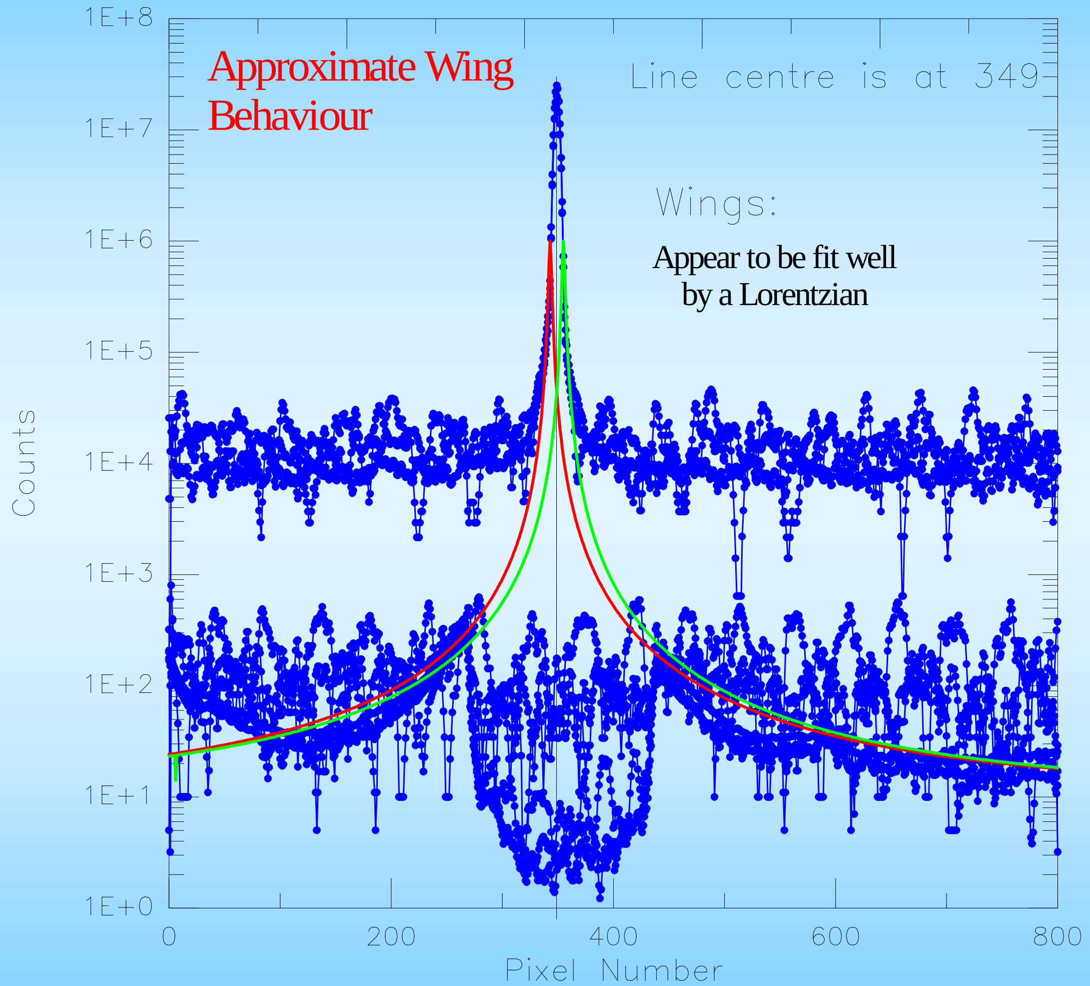


Brewer Stray Light



Courtesy
C. McLinden

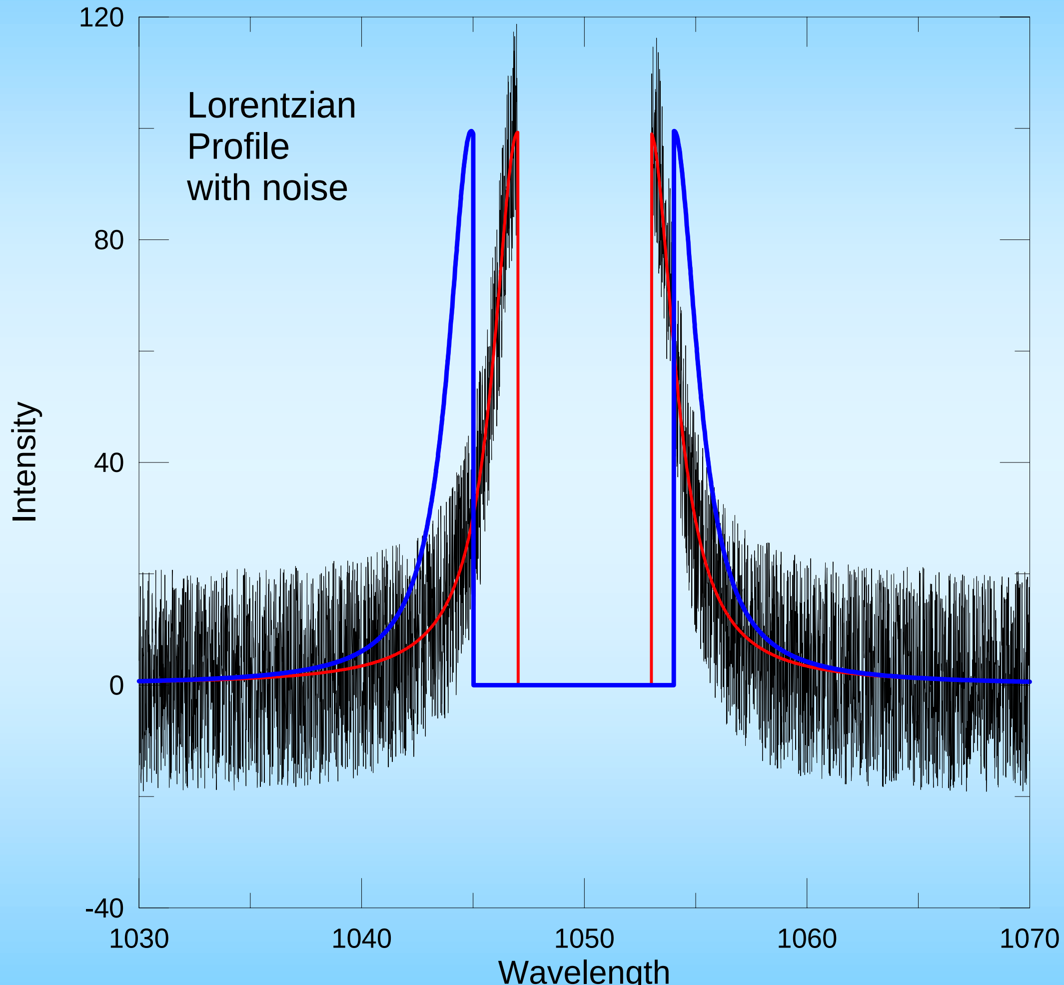
Fitting the Grating Stray Light



Flight gratings characterized in engineering model spectrometer

Note some evidence of etalonning in stray light function

On-orbit Retrieval



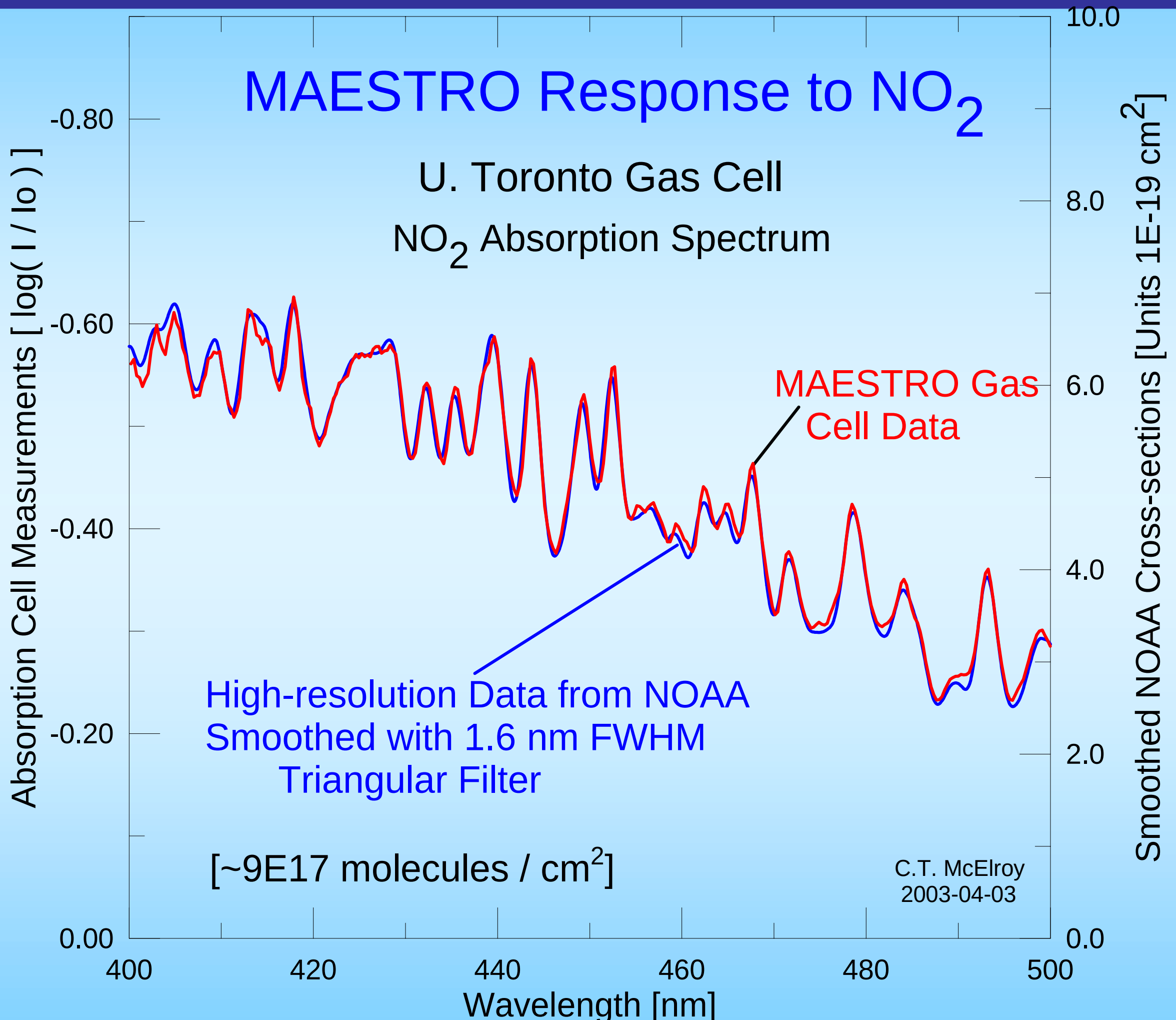
Potential to retrieve instrument characteristics on orbit

Lorentzian left- and right-hand side shapes requires a total of 4 parameters
2 positions, 1 amplitude
1 half-width

MAESTRO Status

- Testing and Characterization Completed
- Characterization Results being Analyzed
- Successful flight of MAESTRO-B last summer (2002)
- Retrieval Code being Written
- Work proceeding on O_2 A- and B-Band modelling
- Final Instrument Code Load – Probably this week
- Commanding protocols under development
- Need to complete retrieval code and install at Waterloo

MAESTRO FM Laboratory NO_2



U. Toronto Instrument Calibration Facility March, 2003

WB-57F

The END!