Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA)

IN-43

End-of-phase Data Review Package

January 20th, 2000

APPENDIX A - KEEP TOGETHER

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Research Support Instruments

GSFC Code 916:
Atmospheric Chemistry and Dynamics Branch

CHyMERA addresses the need for NASA's ESE post EOS missions in the area of atmospheric chemistry

The application of CHyMERA technology is directed towards high spatial resolution/near global coverage measurements of air quality and climate.

CHyMERA technology will result in highly flexible, stable, accurate, and simple instrumentation to:

- ➢Map key chemical constituents in the troposphere to study air pollution events and their transport.
- ➢Track aerosols from industrial and biomass burning to study effects on climate, chemistry, surface radiation and visibility
- ➢Collect data on urban scales (5 km resolution) with global coverage in 1-2 days.

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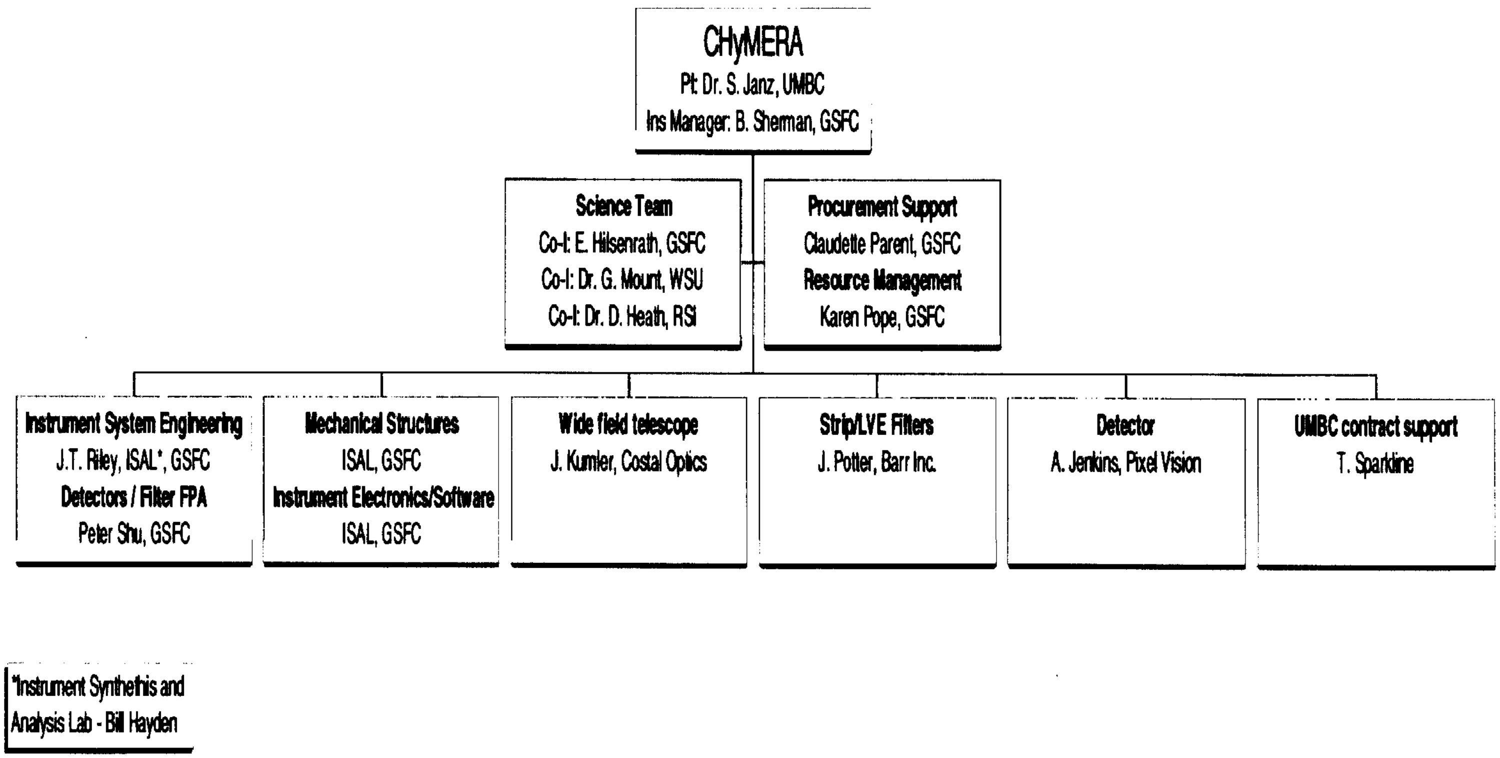
Appendices A. WSU report on NO_2 study.	
B. Vendor filter measurements, CWL and out-of-band.	
C. Vendor lens curvature measurements.	

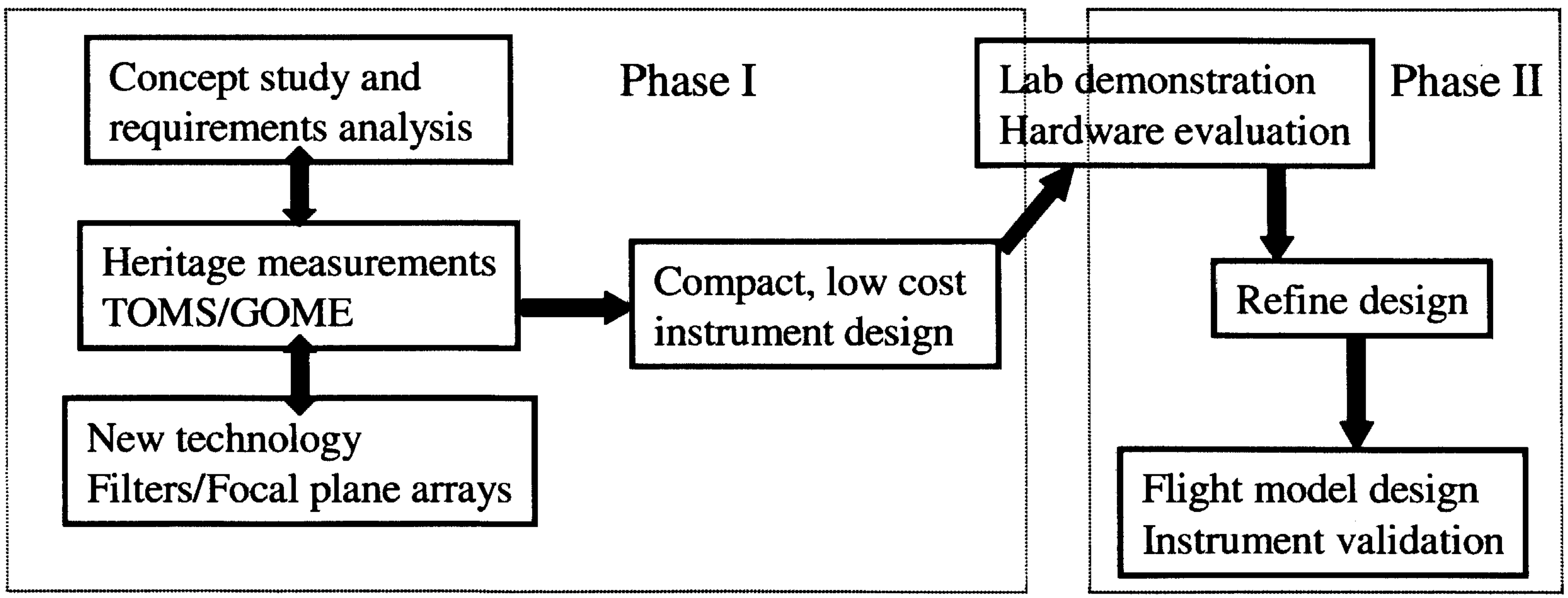
CHyMERA Organizational Chart



1.0 Introduction

1.1 Project Goals - Concept Overview

- Use new technology development of stable interference filters to design compact, low cost imaging filter radiometer for use in low Earth orbit UV remote sensing.
- Improve on state-of-the-art spatial resolution through careful selection of filter channels to maximize system sensitivity.
- 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.



1.2 Project Status Summary

- Requirements analysis milestone completed and reported at midphase review.
  - A requirements analysis was completed to define the performance characteristics needed for hardware specifications and show concept feasibility.
  - Wavelength selection and optical (spatial) parameters were defined along with the detector specifications.
- Hardware procurement of detector, optical, and filter components complete.
  - All sub-systems have been delivered and tested for functionality.
  - Detector delivery delay has delayed sub-system verification by ~2 months.
- Breadboard model complete except for final filter placement.
  - Strip filter array final mounting will be completed in early February.
  - Linear variable array will arrive by the end of January.
- Initial breadboard evaluation has begun.
  - Filter witness sample center wavelength (CWL), bandpass, and integrated out-of-band measurements started.
  - On-axis point-spread function has been measured.
  - Detector noise and functionality has been measured.

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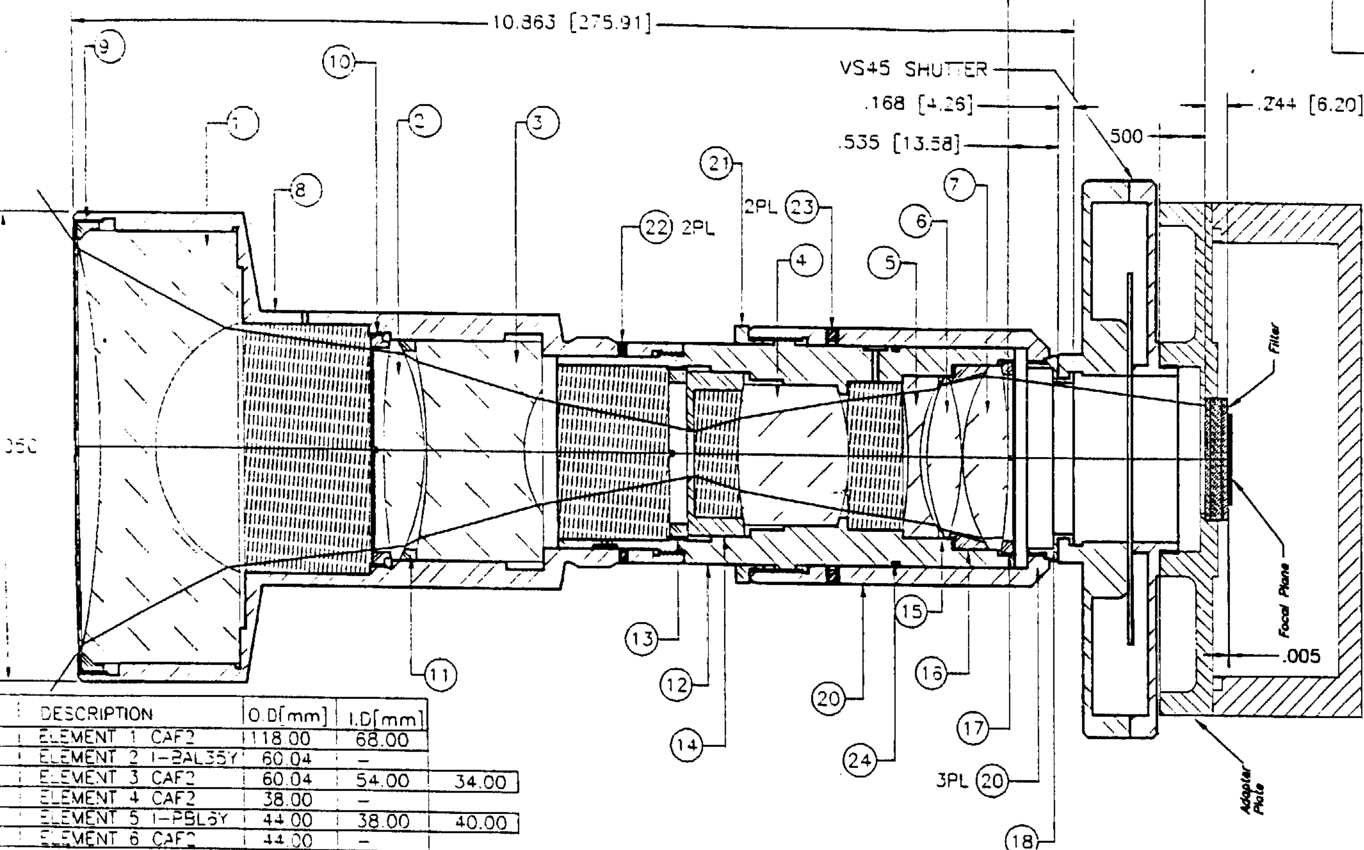
REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVAL
	A	UPDATED PARTS LIST	8-99	C.S.N.
	B	ADDED PARTS 20,21,23 ADDED TOLERANCES TABLE	8-99	C.S.N.



DESCRIPTION	O.D[mm]	I.D[mm]	
ELEMENT 1 CAF2	118.00	68.00	
ELEMENT 2 I-BAL35Y	60.04	–	
ELEMENT 3 CAF2	60.04	54.00	34.00
ELEMENT 4 CAF2	38.00	–	
ELEMENT 5 I-PBL6Y	44.00	38.00	40.00
ELEMENT 6 CAF2	44.00	–	
ELEMENT 7 CAF2	50.00	–	
HOUSING A			
RETAINER 1			
RETAINER 2			
SPACER 1			
HOUSING B			
RETAINER 3			
MARGINAL STOP			
SPACER 2			
SPACER 3			
RETAINER 4			
F MOUNT ADAPTER			
LENS CAP			
ADJUSTMENT MOUNT			
ADJ. LIMITING RING			
#2-56 NYLON TIP SCREW			
#6-32 NYLON TIP SCREW			

ELEMENTS	AIR SPACE[mm]	DECENTER[mm]	TILT(DEG)
1–2	63.00±.10	±.10	±.10
2–3	0.695±.10	±.10	±.10
3–STOP	46.64±.10	±.10	±.10
STOP–4	12.11±.10	±.10	±.10
4–5	16.20±.04	±.03	±.04
5–6	1.95±.04	±.05	±.04
6–7	0.40±.04	±.10	±.10

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND INCLUDE APPLIED FINISH TOLERANCES.
2 PL ±.01 3 PL ±.005 ANGLE ±.5°

MATERIAL: AS PROVIDED

DRAWN BY AUG 25 99 C. NOVOA
CHECKED
DFT SUP
DSN SUP
CH ENGR

COASTAL OPTICAL SYSTEMS, INC.
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407

18.4mm F/4.84 WIDE ANGLE TELECENTRIC LENS ASSY.

B FSCM NO. DWG NO. 9913700 REV B

SCALE: 1/1.5 SHEET 1 OF

2.0 Phase I Results: Requirements analysis initial breadboard results

- Goal (discrete filter method)
  - Maximize sensitivity and stability of predicted trace gas retrievals using a finite set of wavelengths and compare to full spectral (DOAS) technique.
  - Apply results of analysis to set constraints on instrument properties such as:
    - Filter and optical performance.
    - Throughput.
    - Detector specifications.
- Method (NO_2)
  - I. Pair retrievals using Fritz peak data.
  - II. Multi-spectral retrievals using synthetic data and noise level inputs from data measured with the Global Ozone Monitoring Experiment (GOME).

➢ Maximize retrieval sensitivity by varying number, position and/or bandwidth of measurement channels.

2.1 Wavelength selection

2.1.1 NO_2 selection

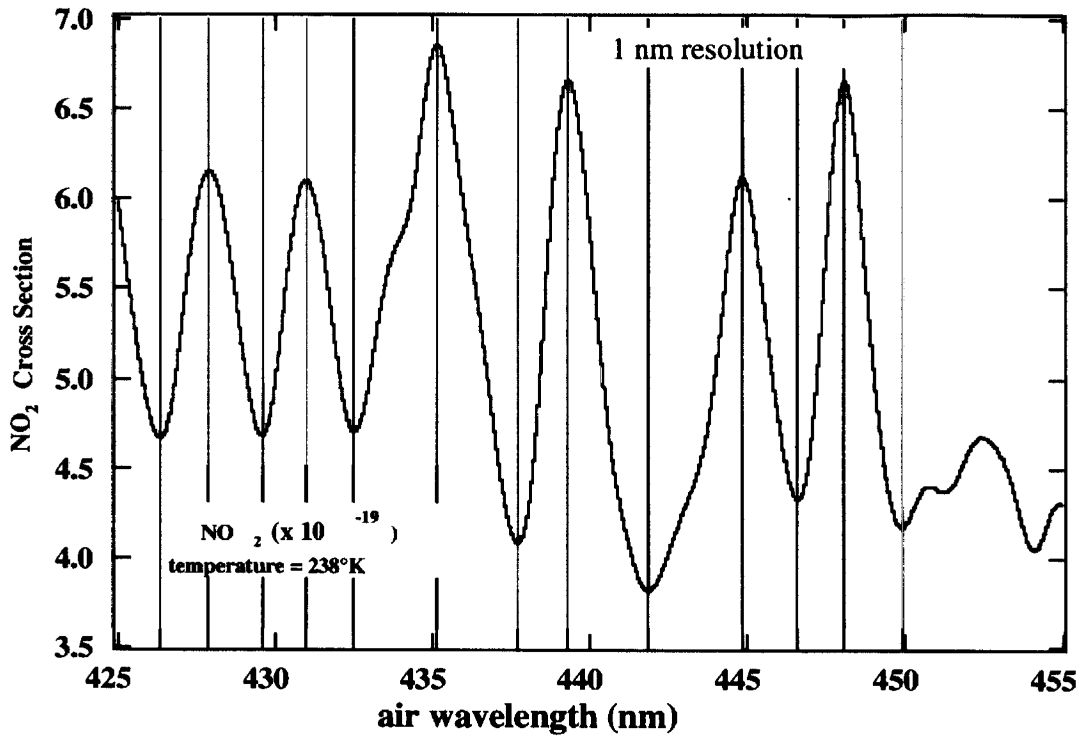


Figure 2.1.1a: 1 nm smoothed NO_2 cross section.
Measured spectra will be a convolution of this structure with others such as Rayleigh,Ring spectra, O_3, O_4, H_2O, and noise.

Best pair derivation using Fritz peak data

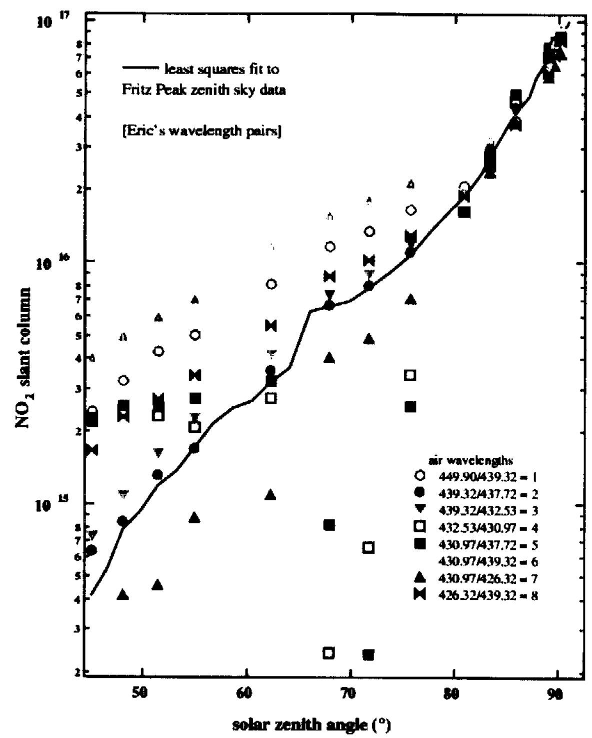


Figure 2.1.1b: Slant column NO_2

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

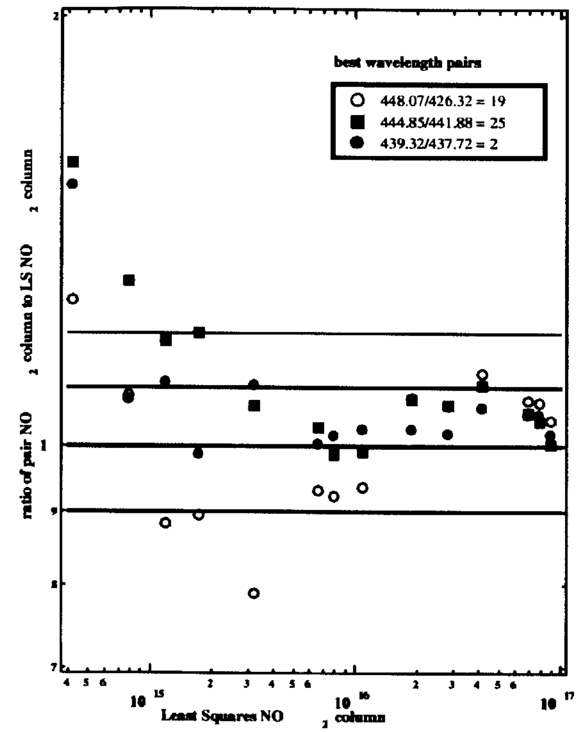


Figure 2.1.1c: Pair wavelength shift sensitivity

Further selection was based on pair ability to maintain a +/- 10% error down to 2e15 cm-2 when shifted by +/- 0.1 nm.

Minimum retrievable NO_2 amounts using multiple wavelengths

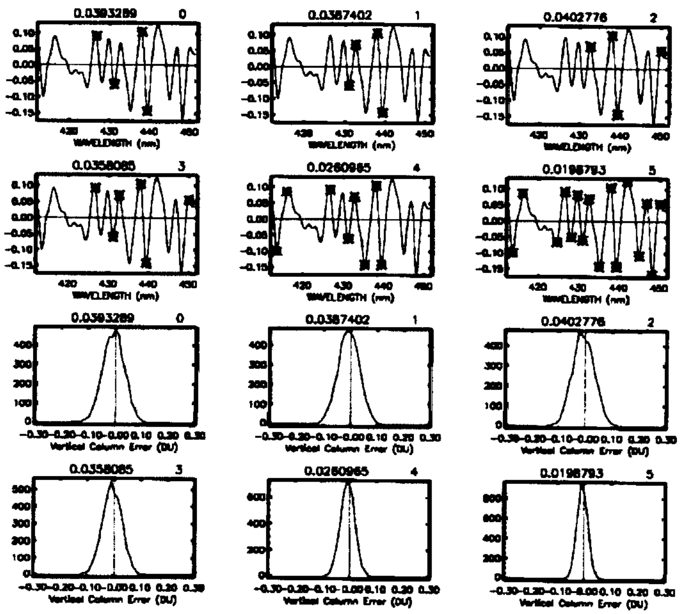


Figure 2.1.1d: Multi-wavelength candidates.

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

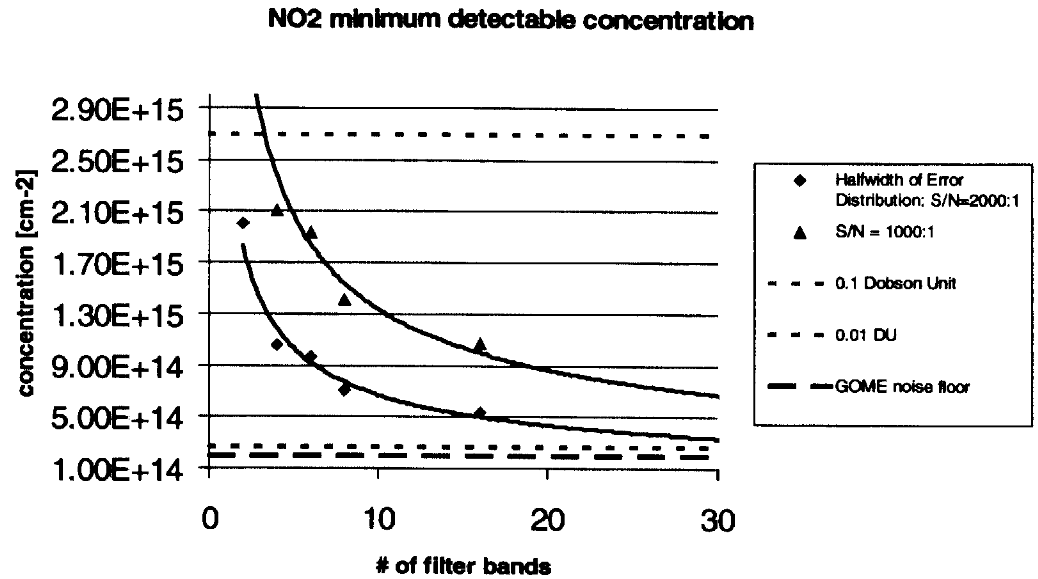


Figure 2.1.1e NO_2 minimum detectibility vs. number of filters.

Retrieval accuracy was not effected by filter band shape. Full DOAS retrieval limited by assumed noise floor (from GOME).

2.1.2 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 which compare well with DOAS technique.

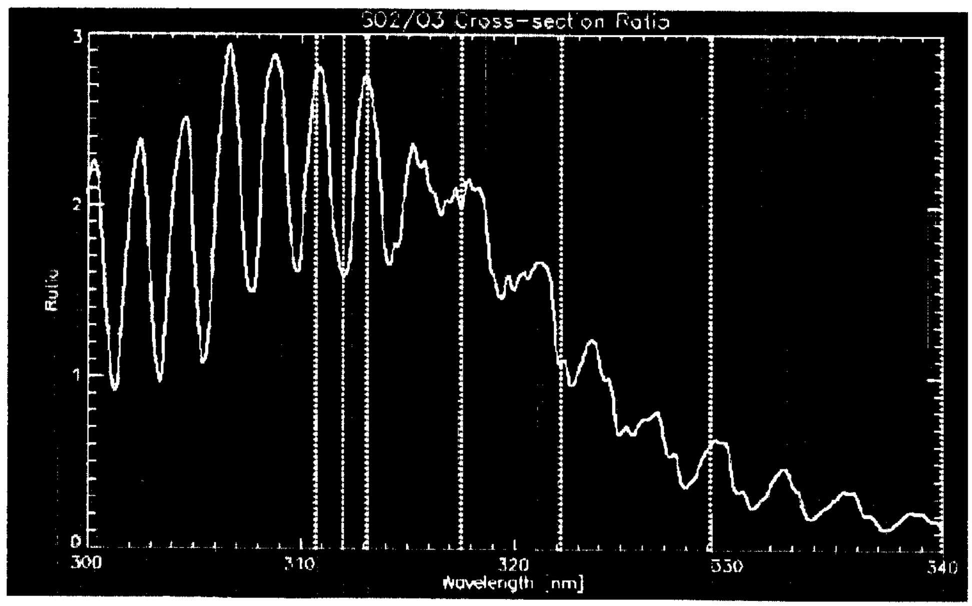
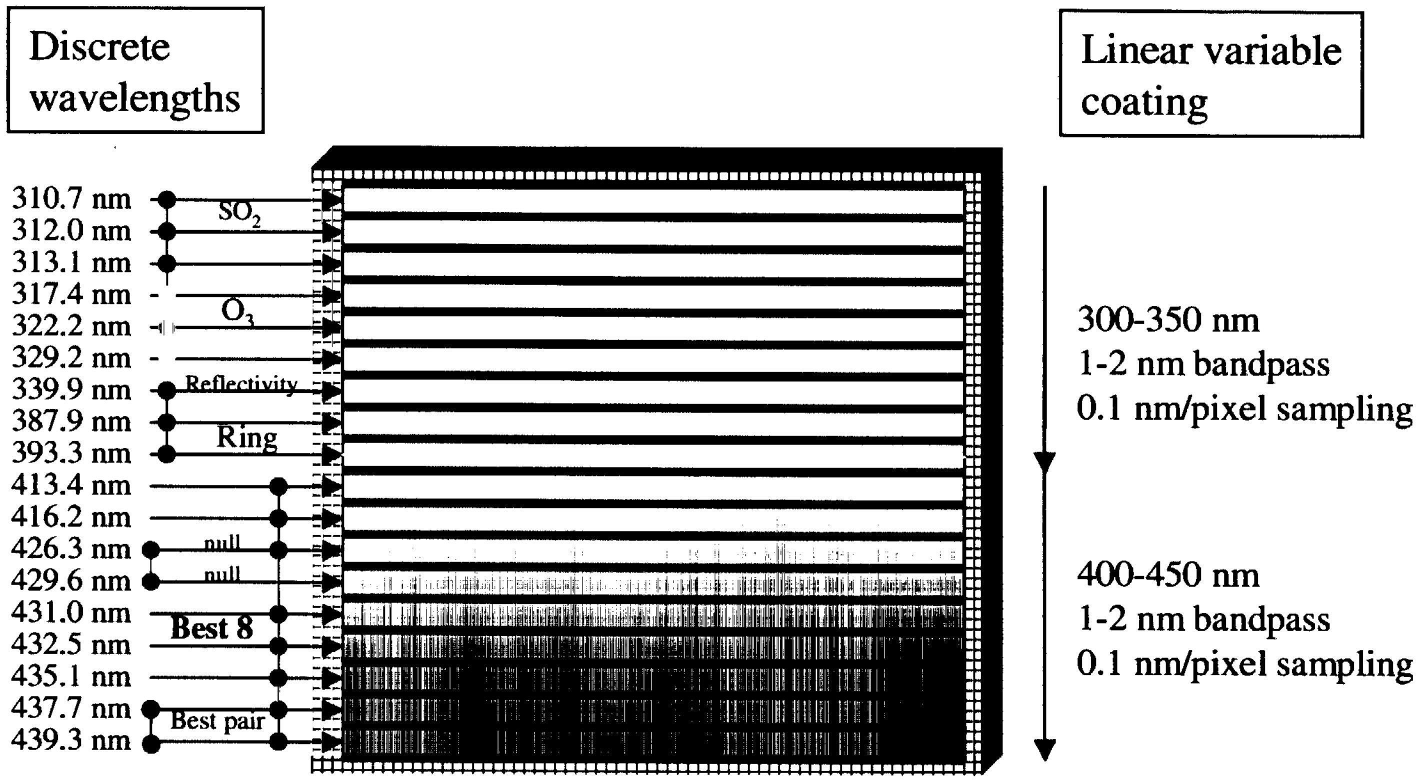


Figure 2.1.2a: Ratio of SO_2 to O_3 cross-sections.

2.1.3 Filter array design and initial test results

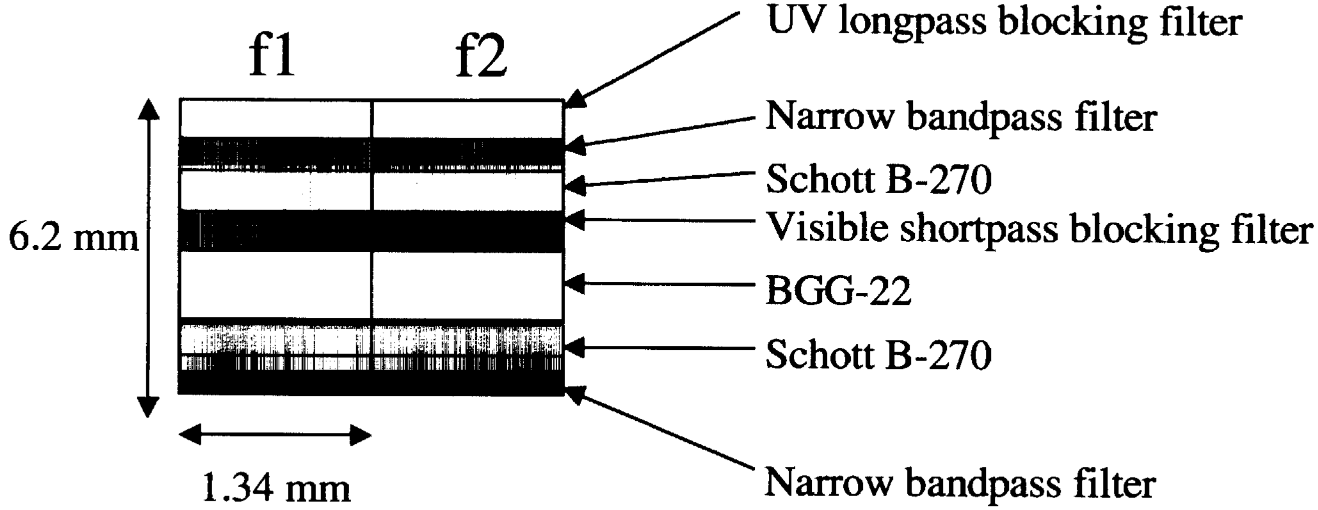
- Two approaches are under investigation:
  - Requirements analysis defined filter specifications:
    - +/- 0.1 nm wavelength accuracy
    - $< 10^{-7}$ out-of-band rejection
    - transmission > 40%
    - 1 nm bandwidth
  - Strip filter method
    - More fully developed and tested technology.
    - 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.
    - Out-of-band and bandpass requirements are a challenge.

Strip filter/Linear variable filter layout

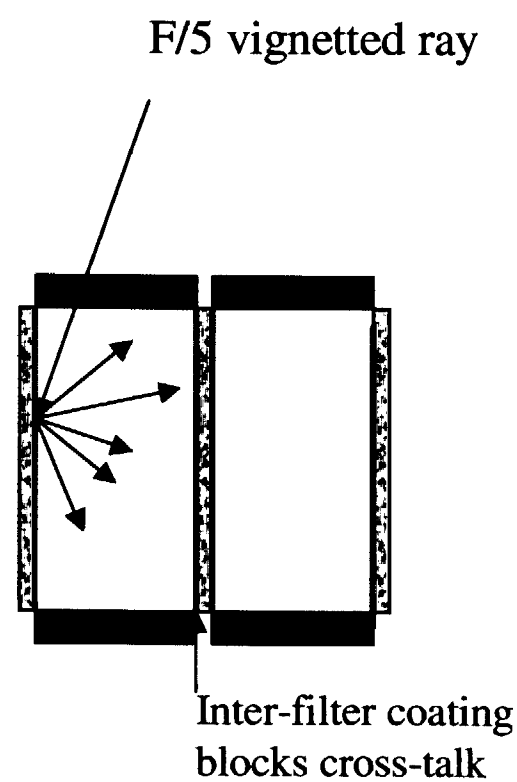


Geometry for 18 filters:
1.34 mm x 33 mm filter strips
(56 x 1024 pixels per filter)

Example of NO_2 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.



Initial breadboard results: strip filter transmission

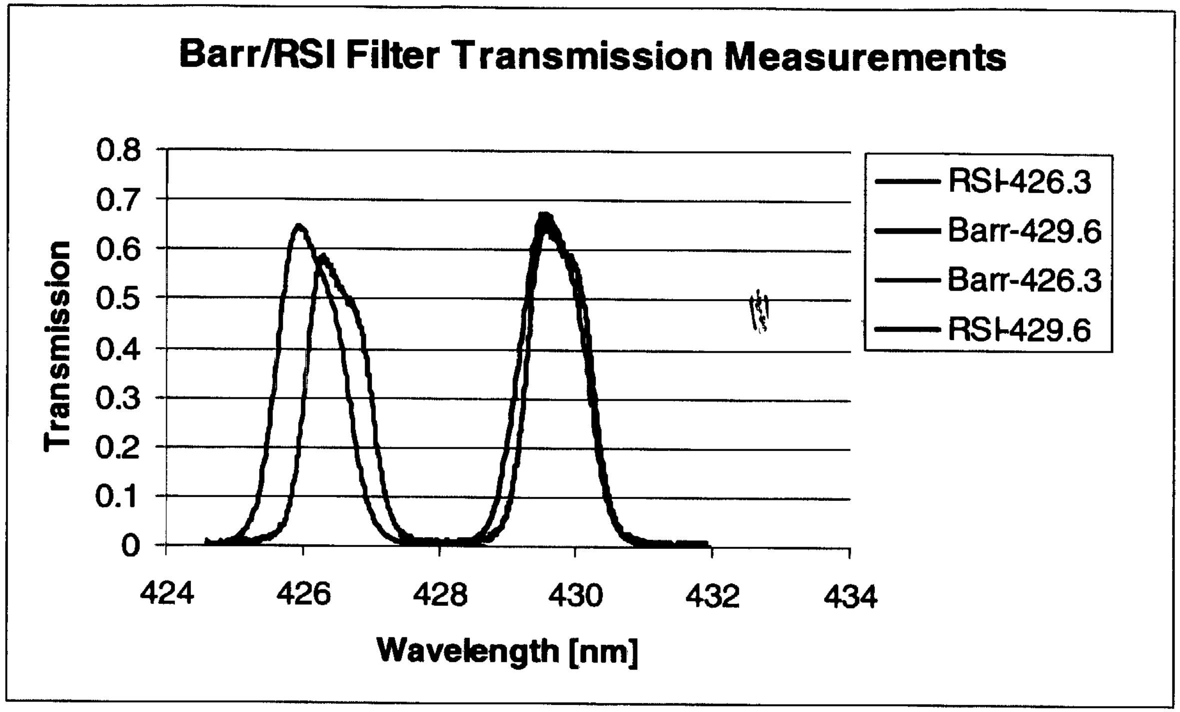


Figure 2.1.3a Witness sample measurements of filter transmission.

•Previous comparison of test samples showed agreement in CWL and bandpass to < 1 angstrom.

•Location of measurement on witness sample may be important. Additional intercomparisons are needed.

Initial breadboard results: strip filter CWL and bandpass

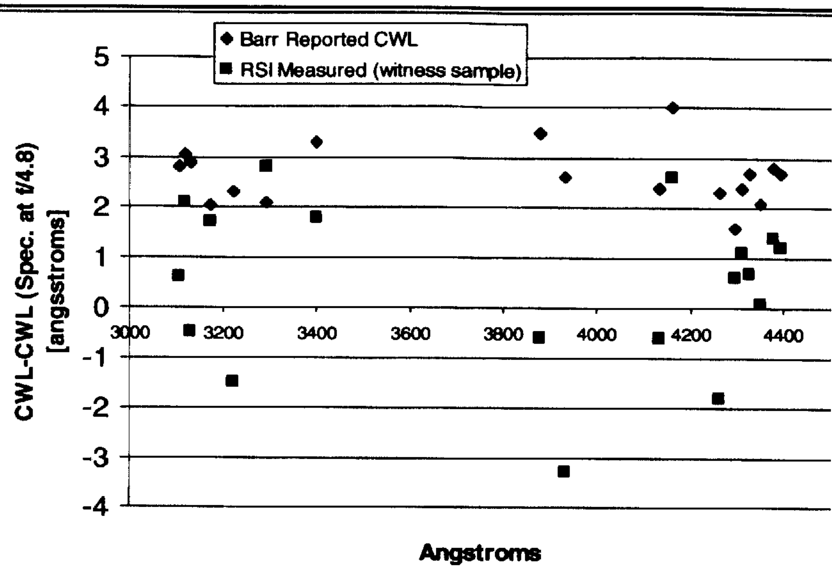


Figure 2.1.3b: Strip filter center wavelengths.

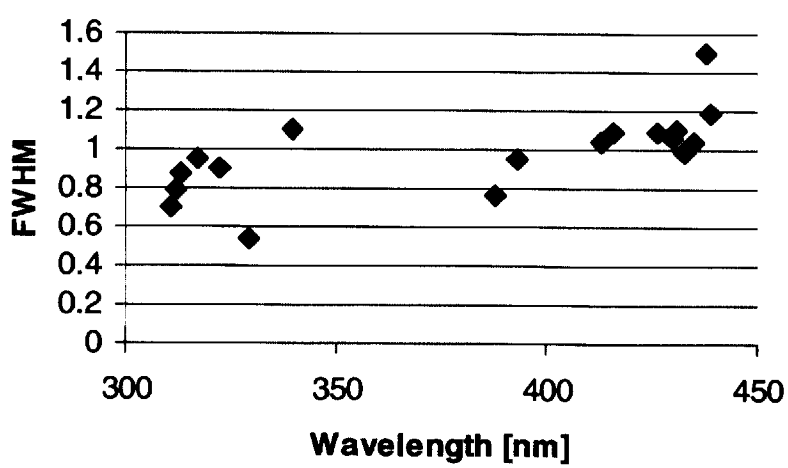


Figure 2.1.3c: Strip filter bandpass.

- Measurements were made at f/8 while instrument will be used at f/4.8: shift = 2.5 angstroms at 310.7 and 3.0 angstroms at 430 nm.

- Center wavelength design tolerance is +/- 0.1 nm and 1.0 nm +/- 0.5 nm for bandpass.

- 8 filters currently outside CWL design tolerance but measurements are preliminary.

- Final wavelength knowledge will be used to estimate sensitivity.

- Linear variable array wavelength characterization will be more straight forward.

Initial breadboard results: strip filter integrated out-of-band

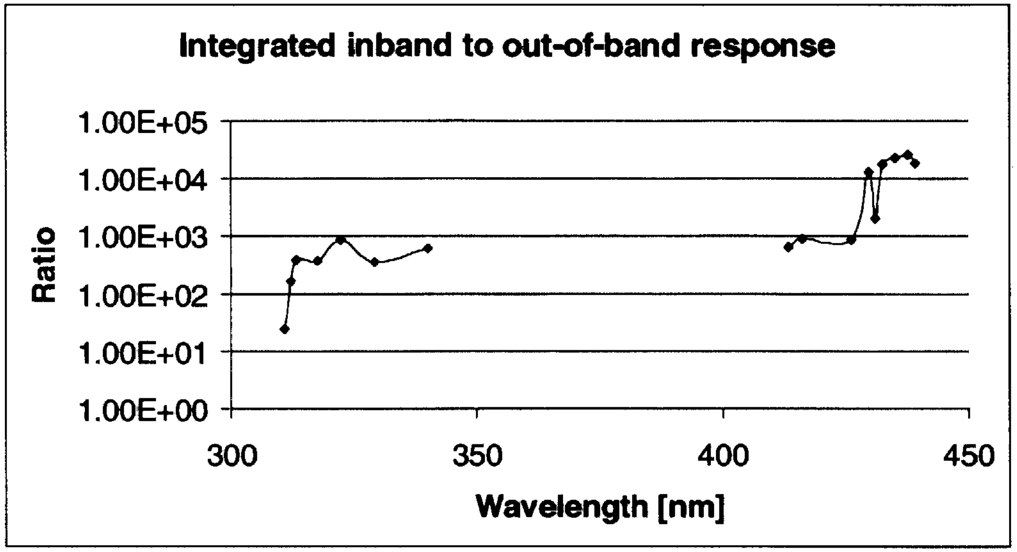


Figure 2.1.3d: Strip filter integrated out-of-band.

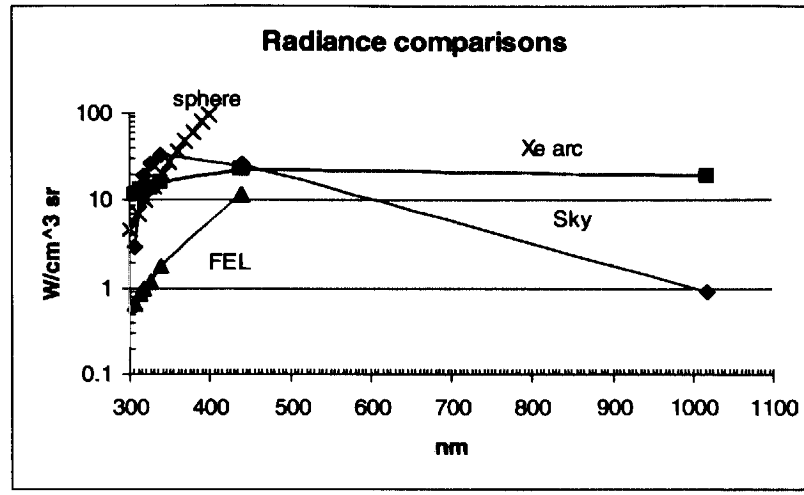


Figure 2.1.3e: Source radiances.

- •Measured using xenon arc source. Represents lower limit of ratio since sky spectral radiance falls off faster than the xenon arc at longer wavelengths due to Rayleigh scattering.
- •Design specification for in-band to out-of-band is > 100.
- •All filters meet this except 310.7 nm channel.

2.2 Design Requirements: Signal-to-noise ratio calculations

- Use expected radiances and calculate instrument throughput to estimate signal-to-noise ratio under typical viewing conditions.

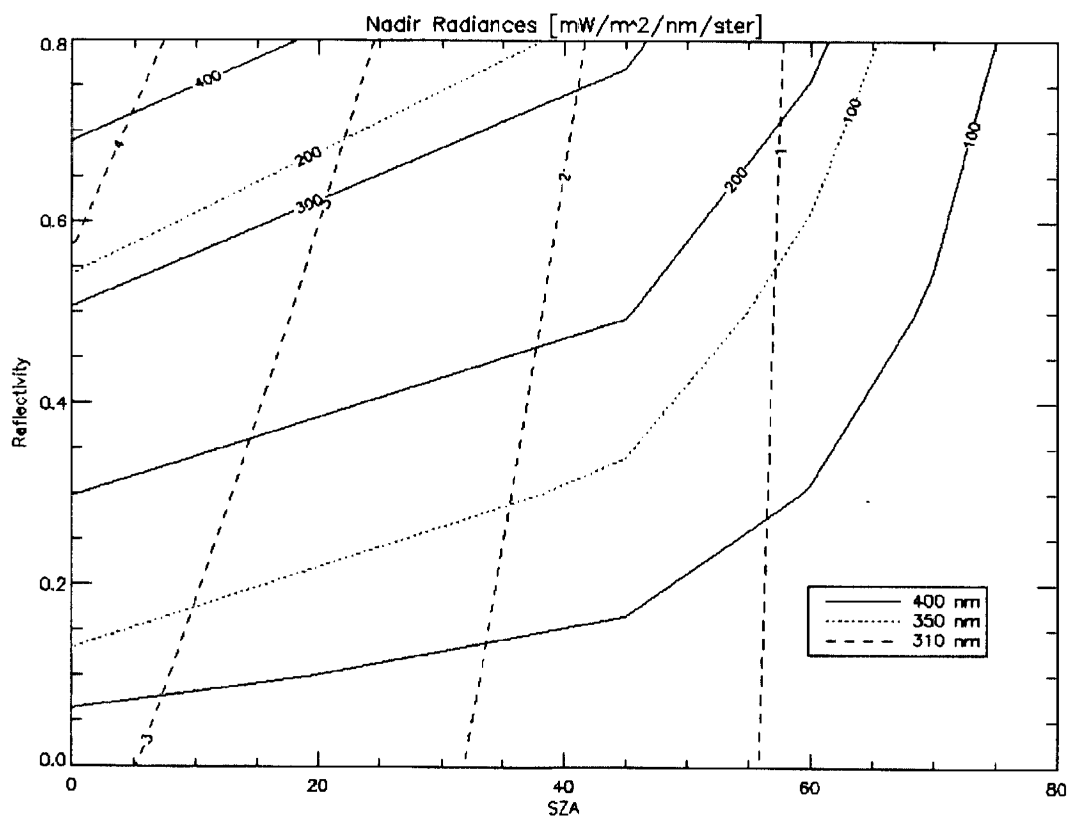


Figure 2.2a: Typical nadir radiance.

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

Achievable spatial resolutions

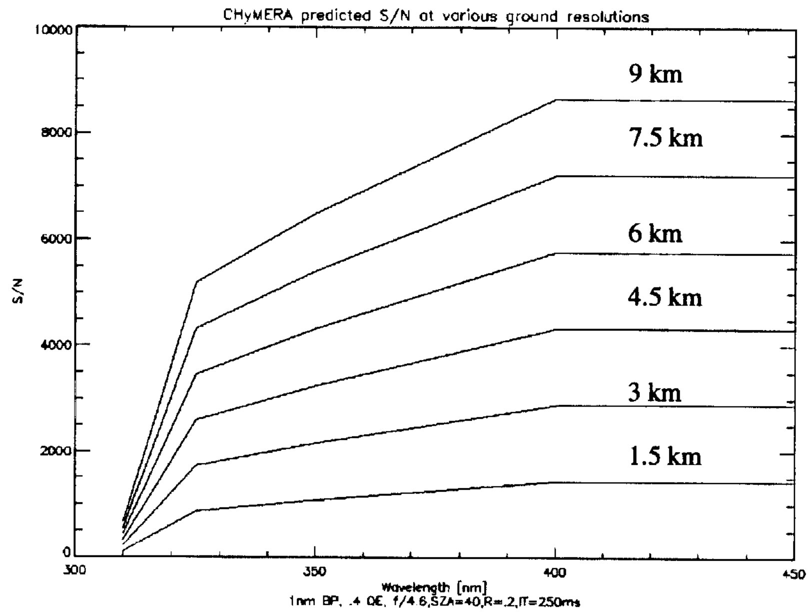


Figure 2.2b: SNR vs. wavelength at various ground resolutions.

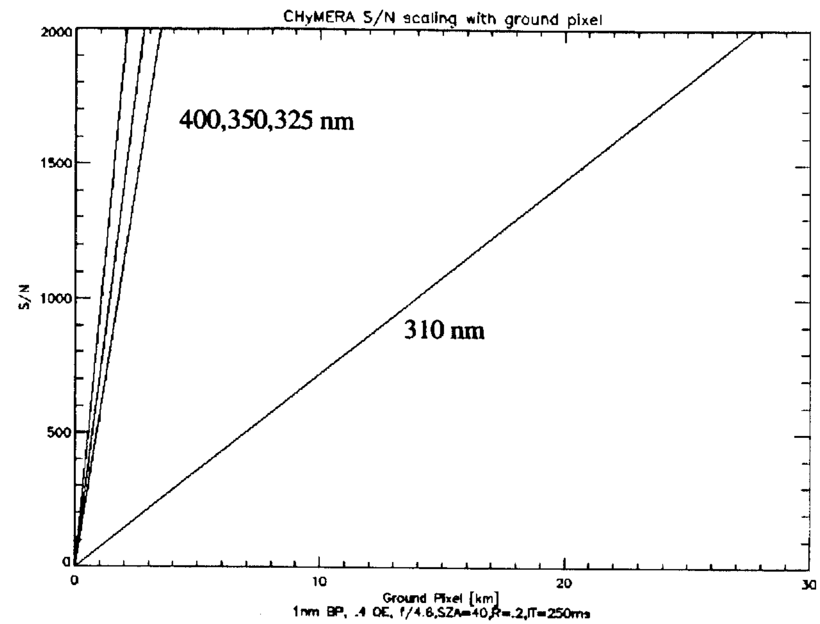


Figure 2.2c: SNR vs. ground resolution at various wavelengths.

- 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

- 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 wavelength selection and bandpass, telescope spot size, and detector parameters.

2.3 Wide field telescope

- 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 (45 degree square).
    - transmission > 80%
    - Telecentric, back-focal length > 50 mm
  - Reflective design
    - Advantages
      - Easier to control ghosts/stray light.
      - Possibly more stable vs. multi-lens system.
      - Broader spectral coverage.
    - Disadvantages
      - Need at least one, probably two lenses to get adequate spot sizes.
      - Tilted focal plane is difficult to handle.
      - Bulky design.
  - Refractive design
    - 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.

2.3.1 Telescope Design

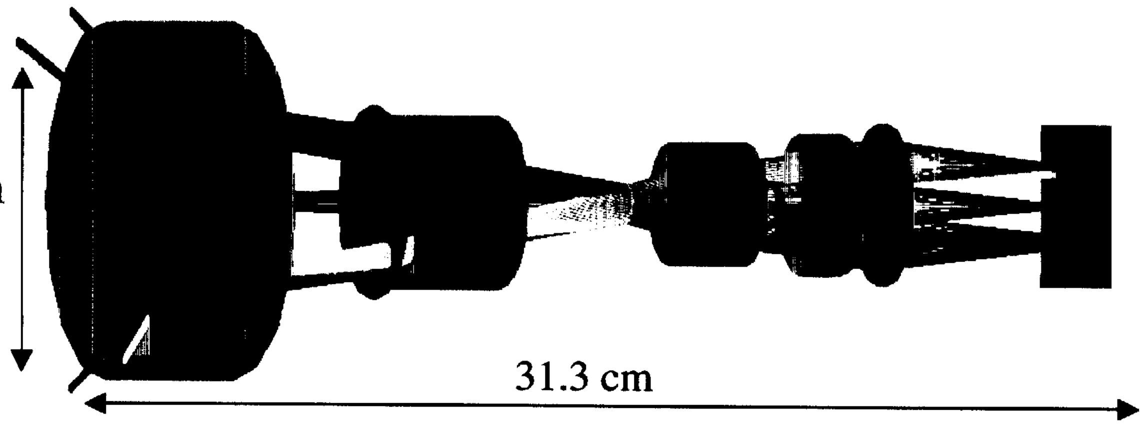


Figure 2.3.1a: Wide angle lens system.

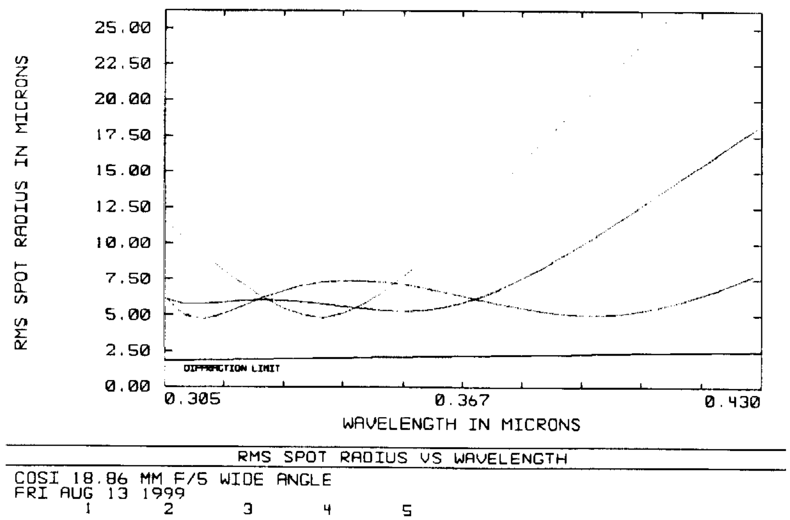


Figure 2.3.1b: Telescope raytrace spot sizes.

- 7-element telecentric design.
- Spot sizes < 1 pixel for all wavelengths over full array.
- Axial color shift minimized.
- 0.5% reflection per surface.
- F/5 system.
- All surface curvatures verified by vendor.

2.3.2 Initial breadboard results: PSF

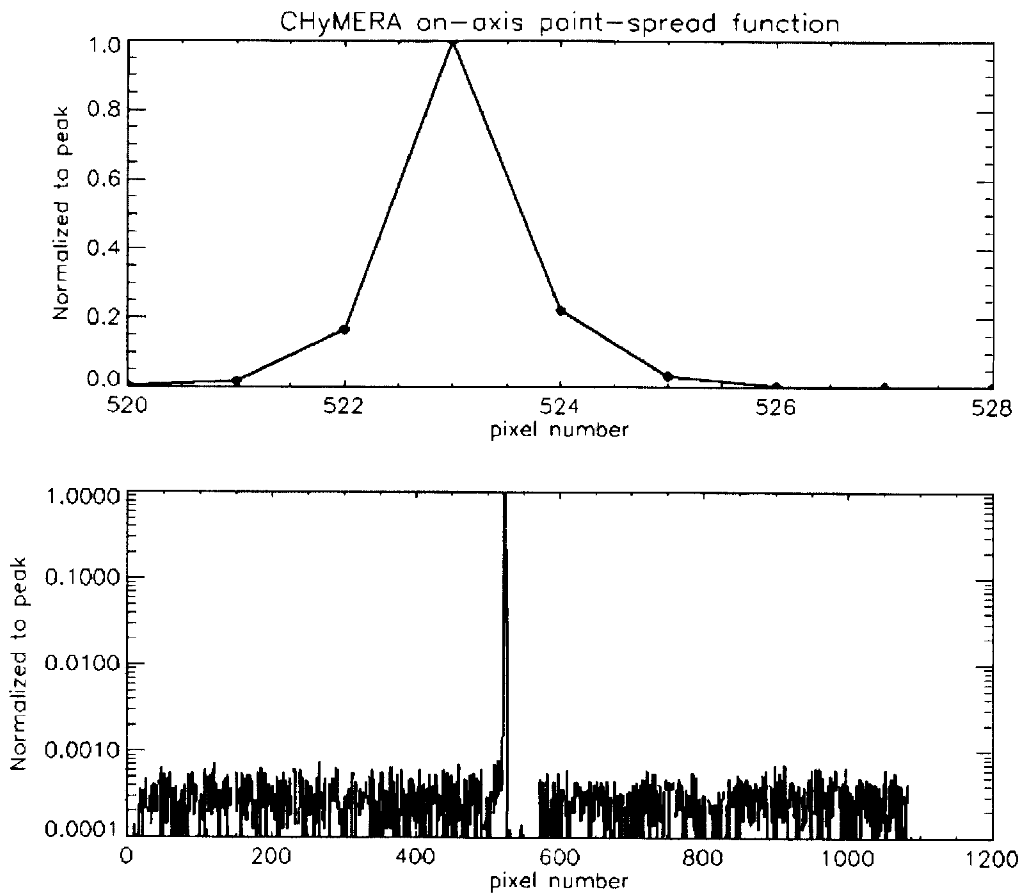


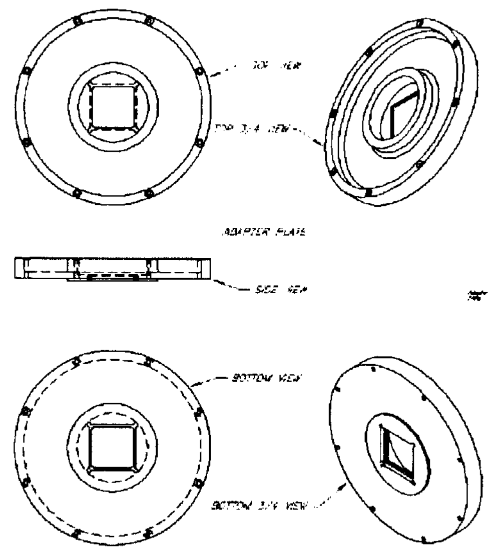
Figure 2.3.2a: Telescope point-spread function.

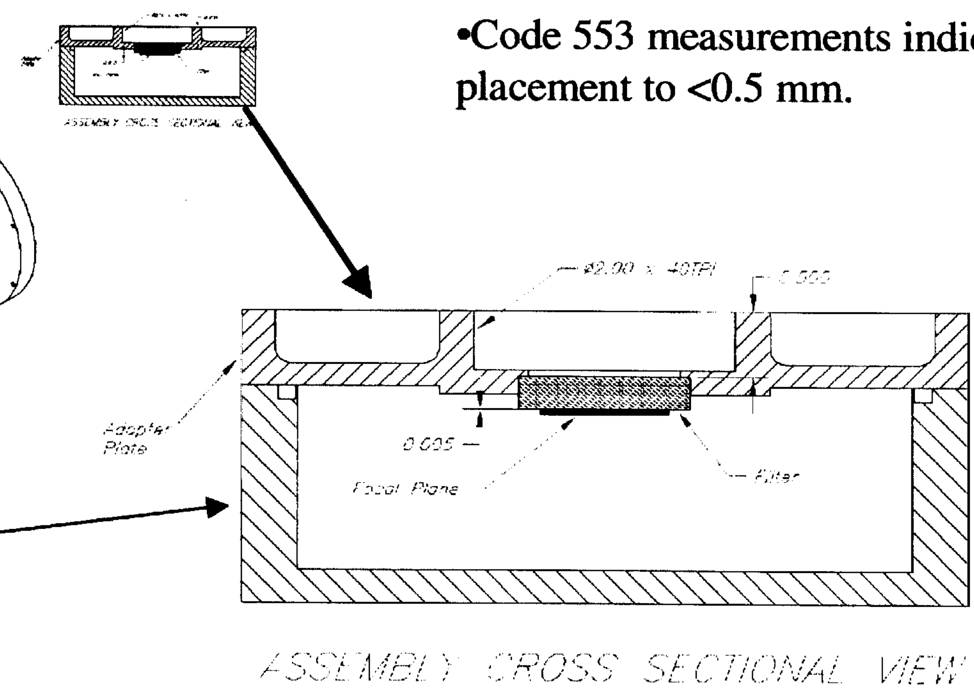
- On-axis PSF measured with 0.2 mm slit at a distance of 2 meters from telescope.
- FWHM = 1 pixel
- Measured with UG11 filter, 5 mm from focal plane.
- 9 frame average allowed background measurement to 5e-4 level of precision.

2.4 Detector system specifications and initial measurements

- 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 was procured. PixelVision quad-readout system has been modified to accept filter array mount.
- Requirements;
  - 1024x1024 pixel format, unsealed detector.
  - Capable of 2 Hz frame rate. (4 output device)
  - non-linearity < 1%.
  - QE > 25%, 300-450 nm. (back-thinned UVAR coated)
  - Programmable clock-rate.
  - Read-noise < 30 electrons.

Filter holder design



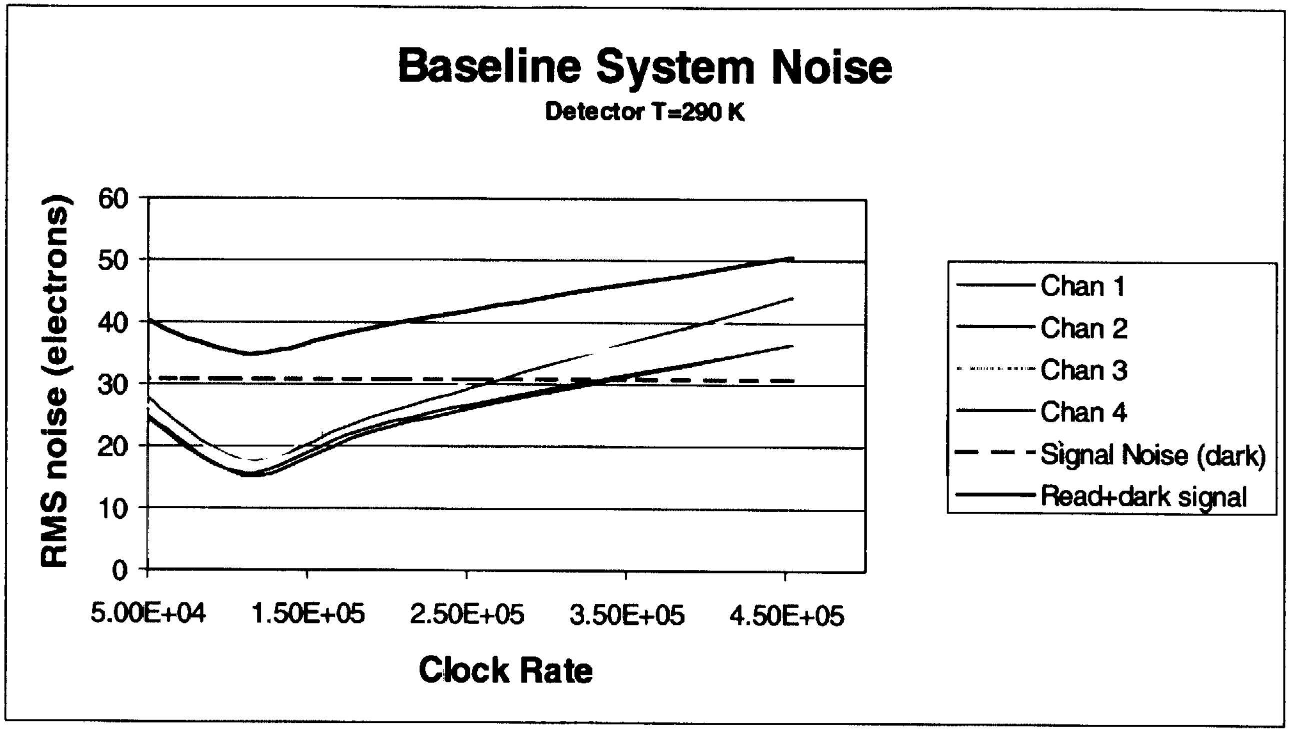


•Requirement on detector placement: <0.8 mm to prevent reflections walking over to adjacent pixel

•Code 553 measurements indicate placement to <0.5 mm.

Pixelvision detector
TEC housing

2.4.1 Detector System: Initial results

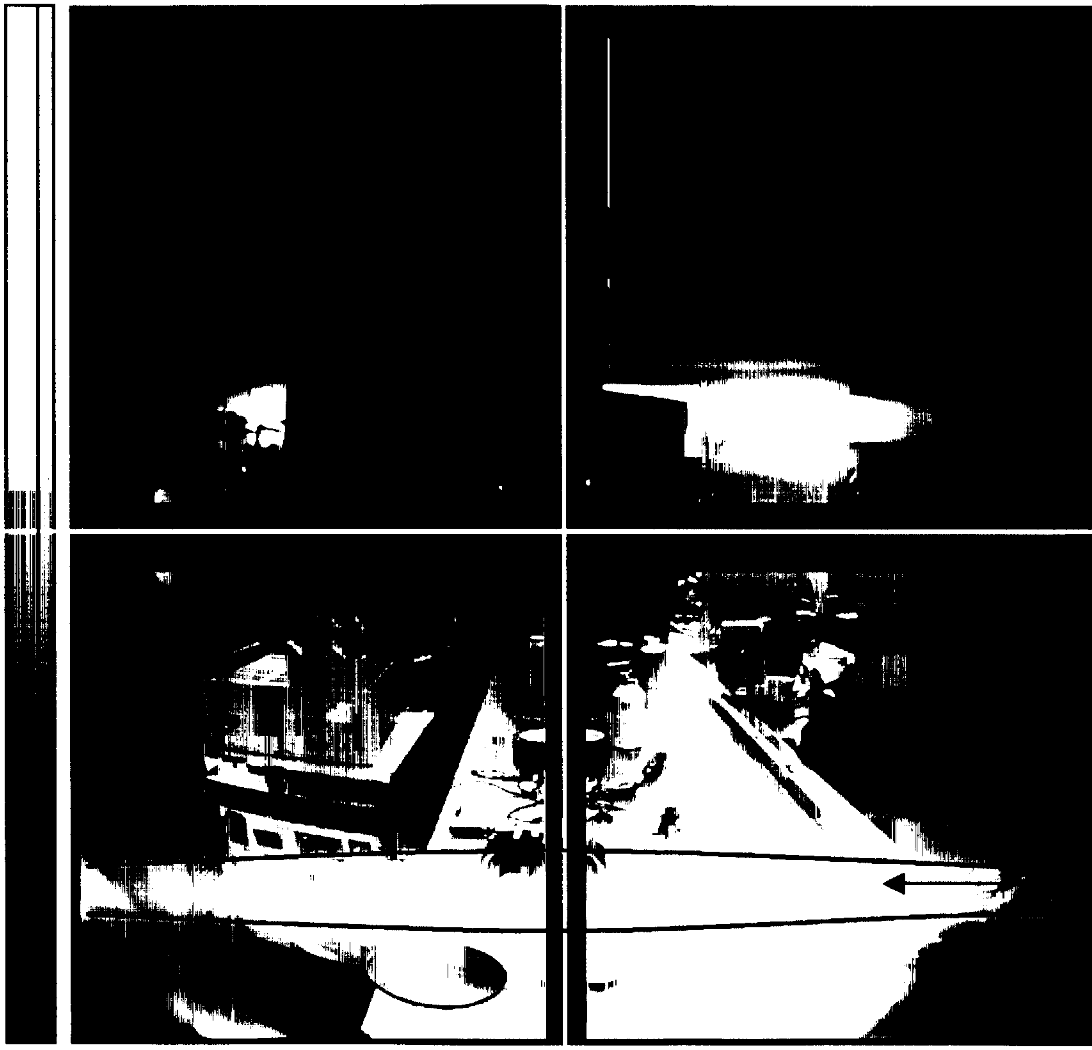


•System baseline noise within specifications.

•Single pixel full-well SNR = 515.

2.5 1st system end-to-end test using strip filter array

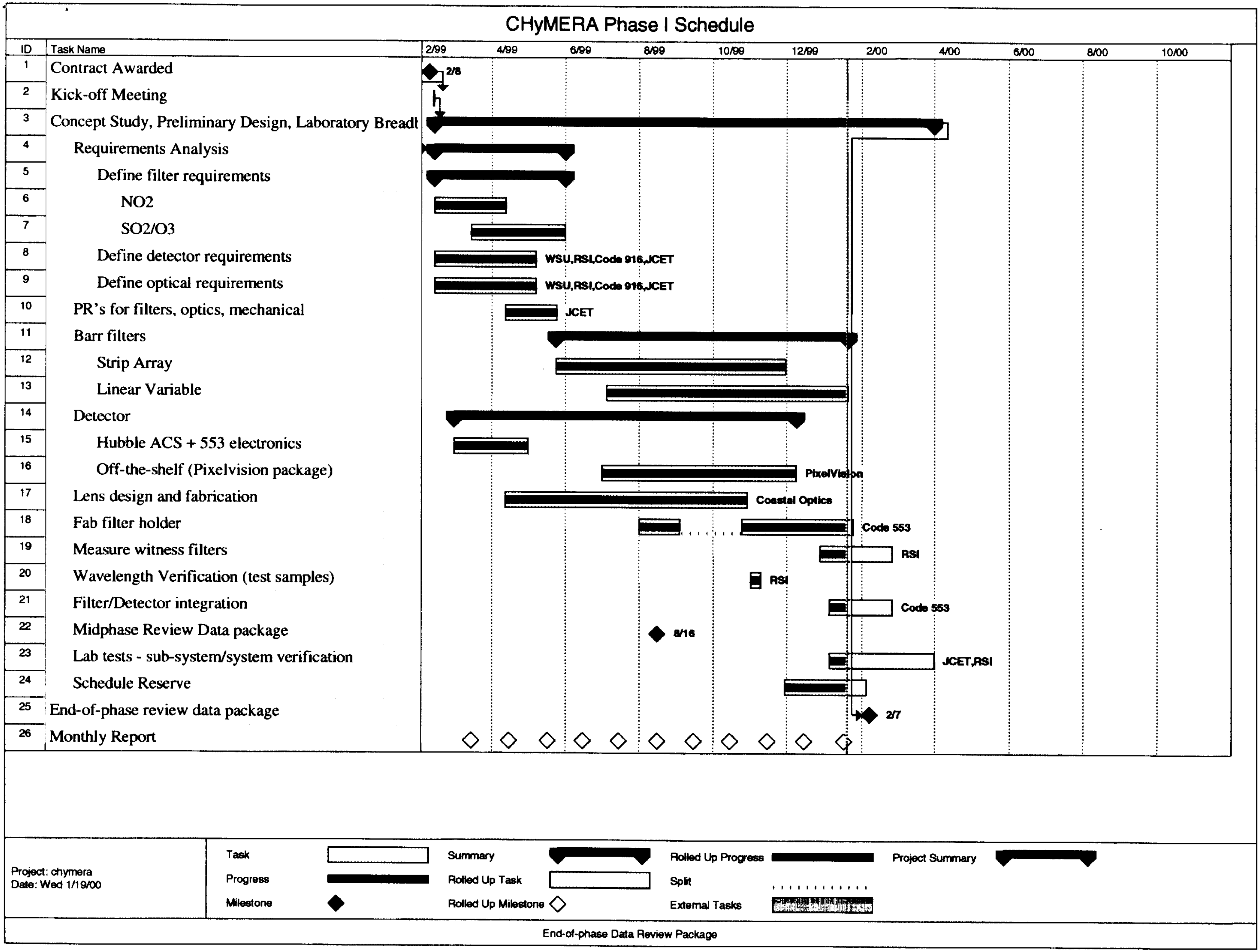
SO_2/O_3 Channels



NO_2 Channels

- Strip filter array temporarily placed 5 mm from focal plane.
- 4 output array architecture is shown as 4 quadrants in full frame.
- Bright band near bottom of frame is a result of overhead lights.

435.1 nm filter: Hg line at 435.88



CHyMERA Phase I Schedule
ID
Task Name
2/99
4/99
6/99
8/99
10/99
12/99
2/00
4/00
6/00
8/00
10/00
1 Contract Awarded
2/8
2 Kick-off Meeting
3 Concept Study, Preliminary Design, Laboratory Breadt
4 Requirements Analysis
5 Define filter requirements
6 NO2
7 SO2/O3
8 Define detector requirements
WSU,RSI,Code 916,JCET
9 Define optical requirements
WSU,RSI,Code 916,JCET
10 PR's for filters, optics, mechanical
JCET
11 Barr filters
12 Strip Array
13 Linear Variable
14 Detector
15 Hubble ACS + 553 electronics
16 Off-the-shelf (Pixelvision package)
PixelVision
17 Lens design and fabrication
Coastal Optics
18 Fab filter holder
Code 553
19 Measure witness filters
RSI
20 Wavelength Verification (test samples)
RSI
21 Filter/Detector integration
Code 553
22 Midphase Review Data package
8/16
23 Lab tests - sub-system/system verification
JCET,RSI
24 Schedule Reserve
25 End-of-phase review data package
2/7
26 Monthly Report
Project: chymera
Date: Wed 1/19/00
Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress
Split
External Tasks
Project Summary
End-of-phase Data Review Package

2.6 Phase I Costs Summary

CHyMERA Phase I Budget Summary
As of 12/30/99

GSFC Budget

JON 916-258-80-16	Allocated	Committed	Balance
Labor	$20,000.00	$20,000.00	$0.00
Hardware	$64,611.00	$64,611.00	$0.00
Branch Assessment	$3,850.00	$3,850.00	$0.00
Division Assessment	$3,850.00	$3,850.00	$0.00
Total	$88,311.00	$88,311.00	$0.00

UMBC Budget

NASA Contract NAS5-99141

UMBC # 055-25816

Category	Planned Total Costs	Costs as of 12/31/99	Total Costs since 2/8/99	Balance
Labor	28,522	2,425	26,548	1,974
Fringes	8,308	659	6,561	1,747
Equipment	125,000	83,317	83,317	41,683
Travel	4,000	-	4,268	(268)
Supplies	10,000	-	3,990	6,010
Subcontracts	95,039	16,043	76,154	18,885
Total Direct	270,869	102,444	200,838	70,031
Total F & A	30,249	5,738	33,512	(3,263)
Total UMBC	301,118	108,182	234,350	66,768

- UMBC spending is on schedule.

- GSFC spending is on schedule for hardware procurement and filter holder design/fab work. Due to the change from custom to off-the-shelf detector development, labor costs associated with designing and building the electronics will be available for ISAL systems support for the 2nd year flight model study.

3.0 Phase II Plans

- Three major activities are planned for the 2nd year phase II portion of the project.
  - Finish sub-system and system verification.
  - Retrieval validation study: ground based measurements at GSFC and WSU.
  - Flight model design study (ISAL).
- This section will describe plans for each of these activities.

3.1 Complete breadboard testing and finalize prototype design

- Continue work begun in the last month of phase I to verify sub-system and system performance specifications.
  - Strip filter wavelength characterization – continue Barr/RSI intercomparison to establish wavelength knowledge for strip filter.
  - Linear variable filter characterization.
  - Full-field point-spread function and distortion mapping.
  - Stray light tests – in-field and out-of-field response will be measured.
  - Detector linearity.
  - System throughput (radiometric calibration) – this will establish overall system sensitivity (response function).
  - System stability.
  - Finalize any design changes.

3.2 Trace gas retrieval validation

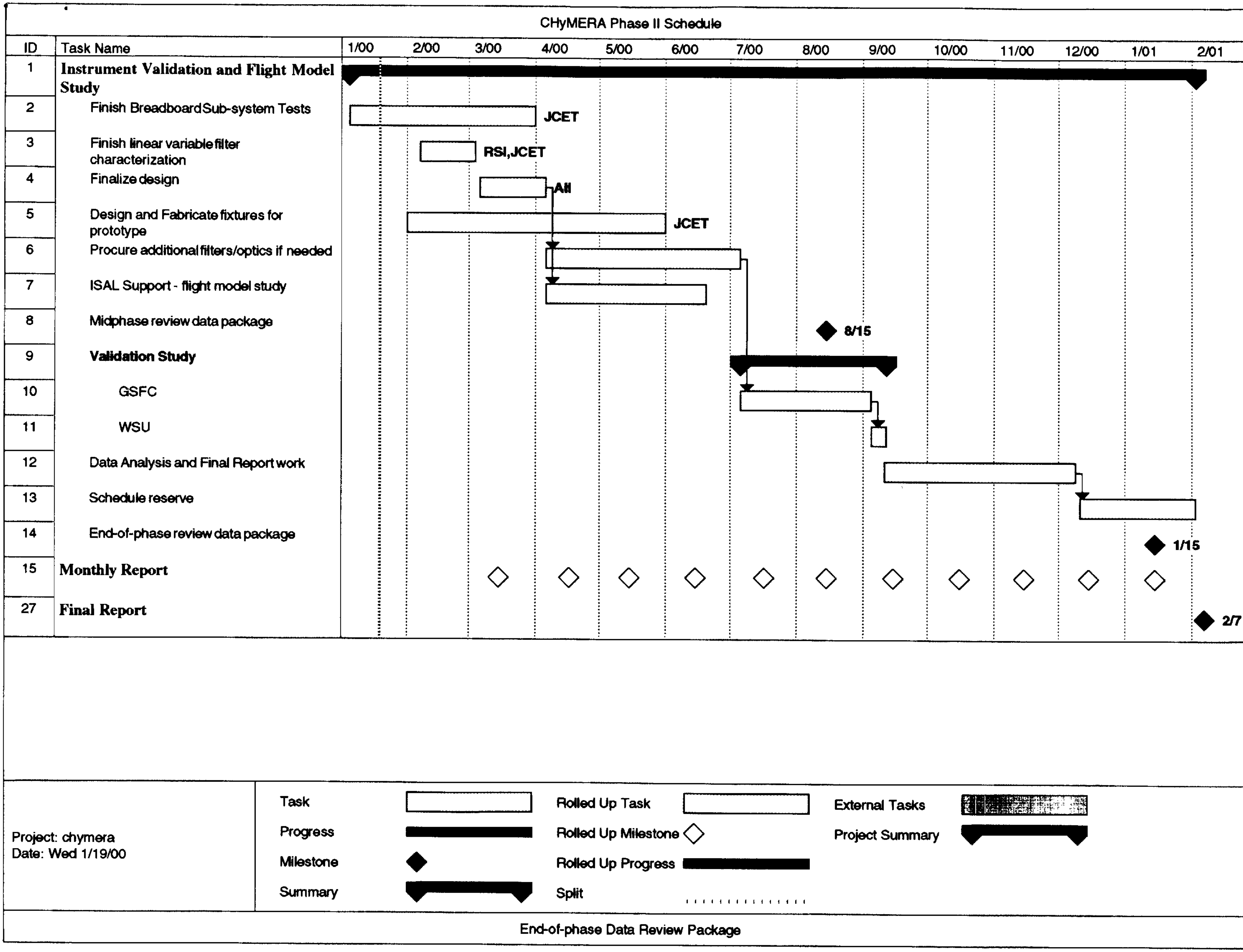
After completion of the sub-system, system, and radiometric verification work, two phases to the validation study will be conducted.

- GSFC
  - O_3 and NO_2 measurements viewing zenith sky radiances. These measurements can be performed over several weeks under differing atmospheric conditions.
  - Absorption cell measurements of NO_2 and SO_2 will be performed to verify retrieval sensitivity.
- WSU
  - Side-by-side NO_2 measurements with established instrumentation will be performed in collaboration with Dr. G. Mount at Washington state.

3.3 Instrument Synthesis and Analysis Lab (ISAL)

ISAL will work with PI and CO-I's to perform a detailed flight model systems analysis to include:

- Thermal-mechanical design and analysis.
- Optical design – including stray-light analysis and baffle design.
- Electrical design and analysis.
- CCD/FPA packaging and electronics.
- Computer/Data interface – including compression and operational schemes to reduce data rate.
- Cost and schedule.



CHyMERA Phase II Schedule
ID
Task Name
1/00
2/00
3/00
4/00
5/00
6/00
7/00
8/00
9/00
10/00
11/00
12/00
1/01
2/01
1 Instrument Validation and Flight Model Study
2 Finish Breadboard Sub-system Tests
JCET
3 Finish linear variable filter characterization
RSI,JCET
4 Finalize design
All
5 Design and Fabricate fixtures for prototype
JCET
6 Procure additional filters/optics if needed
7 ISAL Support - flight model study
8 Midphase review data package
8/15
9 Validation Study
10 GSFC
11 WSU
12 Data Analysis and Final Report work
13 Schedule reserve
14 End-of-phase review data package
1/15
15 Monthly Report
27 Final Report
2/7
Project: chymera
Date: Wed 1/19/00
Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress
Split
External Tasks
Project Summary
End-of-phase Data Review Package

Phase II costs summary

CHyMERA Phase II Budget Summary	
	GSFC Budget
	Planned
ISAL Support - contractor labor	$80,000.00
Hardware - lab equipment	$15,436.00
Branch Assessment	$2,863.08
Division Assessment	$2,863.08
Total	$101,162.16
	UMBC Budget
NASA Contract NAS5-99141	
UMBC # 055-25816	
	Planned
Category	Total Costs
Labor	29,378
Fringes	8,641
Equipment	55,000
Travel	4,000
Supplies	15,000
Subcontracts	95,937
Total Direct	207,956
Total F & A	17,106
Total UMBC	225,062

- Primary portion of 2nd year GSFC funding will go to ISAL support for flight model study and design.
- UMBC funds will support CO-I subcontractor work in test and validation of instrument.
- Additional optical components and a spare detector will be purchased through UMBC

4.0 Rationale for project continuation

4.1 Phase I conclusions: Primary findings, technology development, critical issues:

- The requirements analysis has shown the feasibility of achieving high spatial resolution trace gas retrievals (suitable to detect tropospheric amounts) using a low-cost compact filter radiometer design.

- Technology developments in hardened interference filter fabrication (particularly in the UV) and linear variable UV coatings have enabled filter radiometers to approach double monochrometer level performance parameters.

- High-speed CCD and related data systems and storage have enabled a hyperspectral imaging approach to precision radiometric measurements.

- ISAL support will take prototype concept and develop a flight model design for the final report. Concept has been proposed as the High Resolution Aerosol and SO_2 Experiment (HASE) for University Earth System Science (UNESS) mission.

- Initial test measurements have identified no critical issues that would prevent successful completion and validation of a prototype instrument.

Appendix A – Washington State University NO_2 Study

- NO_2 pair evaluation
- Null pair evaluation
- Wavelength shift problems
- Filter calculations
- Atmospheric temperature vs cross section effects

First Year Report: Washington State University

CHyMERA
Compact Hyperspectral Mapper for Environmental Remote Sensing Applications

George H Mount
Laboratory for Atmospheric Research
Dept. of Civil and Environmental Engineering
Washington State University
Pullman, WA 99164-2910

23 December 1999

I. Work Accomplished to Date

Funding from the CHyMERA project paid for 6 weeks of PI salary and travel.

a) participated in the detailed definition, on-going development, and optical design of the CHyMERA project and instrument
- attended two meetings at Goddard Space Flight Center (February, May)
- prepared several reports (below)

b) performed calculations for determination of NO_2 sensitivity levels given instrument performance parameters
- NO_2 pair evaluation
- null pair evaluation
- wavelength shift problems
- filter calculations
- atmospheric temperature vs cross section effects

c) reports prepared for the CHyMERA group (appended to this document):

1. 23 Feb 1999 - NO_2 calculations for temperature dependence of cross sections; comparison of 1 and 2 nm spectral resolution and effect on wavelength pairs
2. 25 Feb 1999 - specification of central NO_2 filter wavelengths and errors
3. 12 March 1999 - NO_2 central wavelength pairs (preliminary)
4. 24 March 1999 - NO_2 central wavelength pairs
5. 26 March 1999 - Effect of shifts in filter bandpass on derived NO_2
6. 30 March 1999 - Null pair specification
7. 7 April 1999 - NO_2 central wavelength pair calculations
8. 30 May 1999 - NO_2 atmospheric temperature dependence problems

II. Plans for Second Year

Funding from the CHyMERA project will pay for 6 weeks of PI salary and travel.

a) continue NO_2 sensitivity calculations as required

b) participate in calibration and validation of the CHyMERA instrument

- participate in meetings and laboratory work at GSFC
- bring the WSU ground based NO_2 instrument up to speed for comparison with the CHyMERA instrument at WSU. This instrument has many years of operation providing excellent ground based NO_2 abundances.

- the instrument has not been run for over two years, so a complete checkout will be required
- relocation of the instrument from the laboratory to observing area will be required
- set up laboratory space for the CHyMERA team
- be prepared to reduce the data from the WSU instrument
- compare the reduced WSU instrument data with that from CHyMERA
- be prepared to host the CHyMERA team

CHyMERA NO_2 Calculations
G. H. Mount
23 February 1999

Response to some of the action items from the 11-12 February meeting:
Note: all wavelengths in this report are air wavelengths.

1. Temperature Dependence of Cross Sections, and data reduction problems

The NO_2 cross sections are temperature dependent. Figure 1 below shows reduction of the ratio of zenith sky data taken at 90° and 83° solar zenith angle (real data) at about 0.6 nm resolution using room temperature NO_2 cross sections. Since the NO_2 layer is at about 27 km altitude in the stratosphere (temperature 230 - 240°K), use of room temperature cross sections is inappropriate (but commonly used by many groups). It produces a systematic residual in the least squares fitted spectrum that shows clear spectral structures, all caused by removal of a wider than physically correct NO_2 cross section from the narrower stratospheric NO_2 lines. Virtually all of the structure shown here is real, not noise, and can be easily deduced from the warm/cold cross section data.

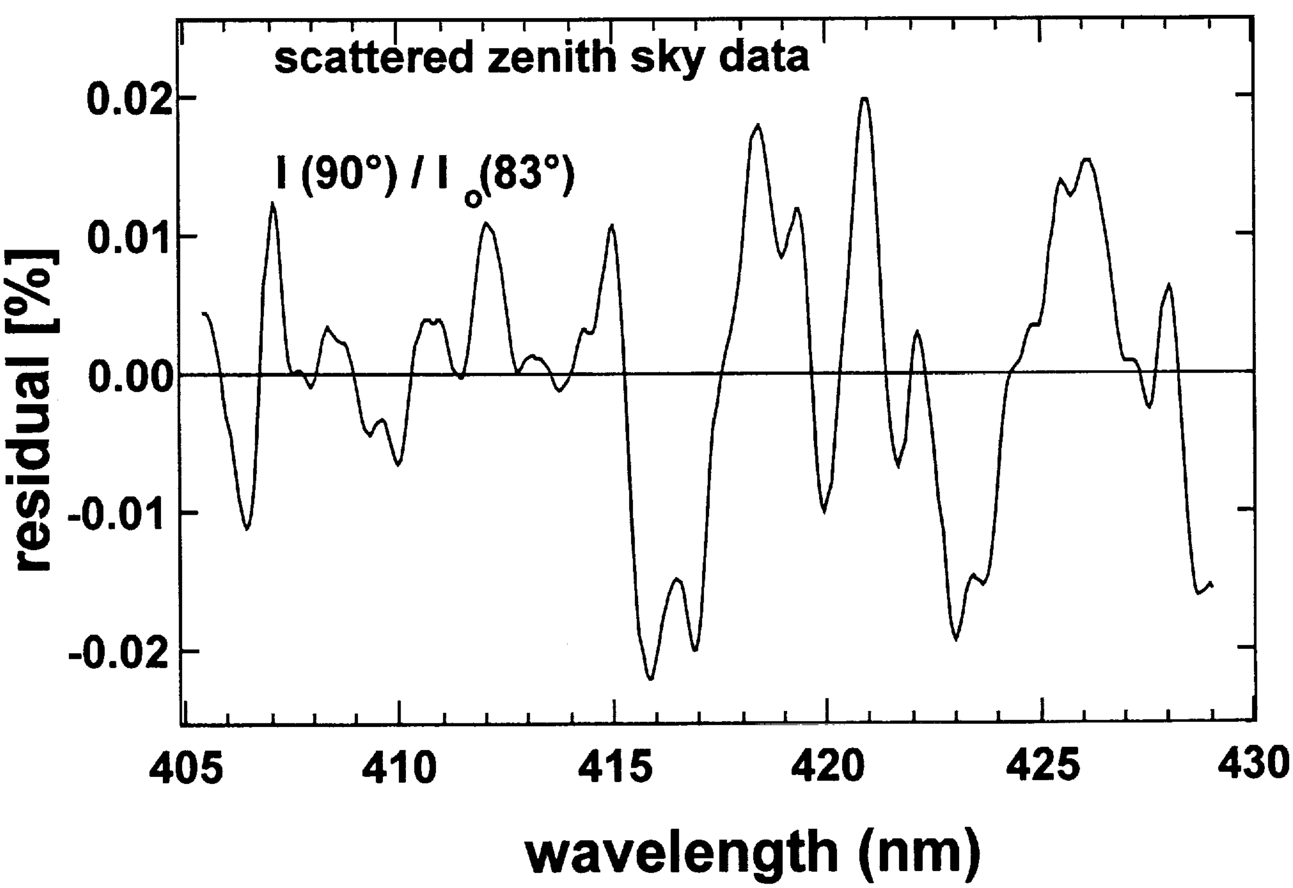


Figure 1. The reduced ratio of a 90° and 83° zenith sky measurement made at Fritz Peak Observatory with the NOAA NDSC instrument (now at WSU). The structure is caused by removal of a room temperature NO_2 cross section from cold stratospheric NO_2 data.

Figure 2 shows high resolution temperature dependence at stratospheric temperature - room temperature to 240°K, the value that we are choosing for the CHyMERA data analysis. The warmer lines are wider and show shallower peaks and valleys. This is high resolution and the differences are clear and large. At lower resolution the effect will be reduced.

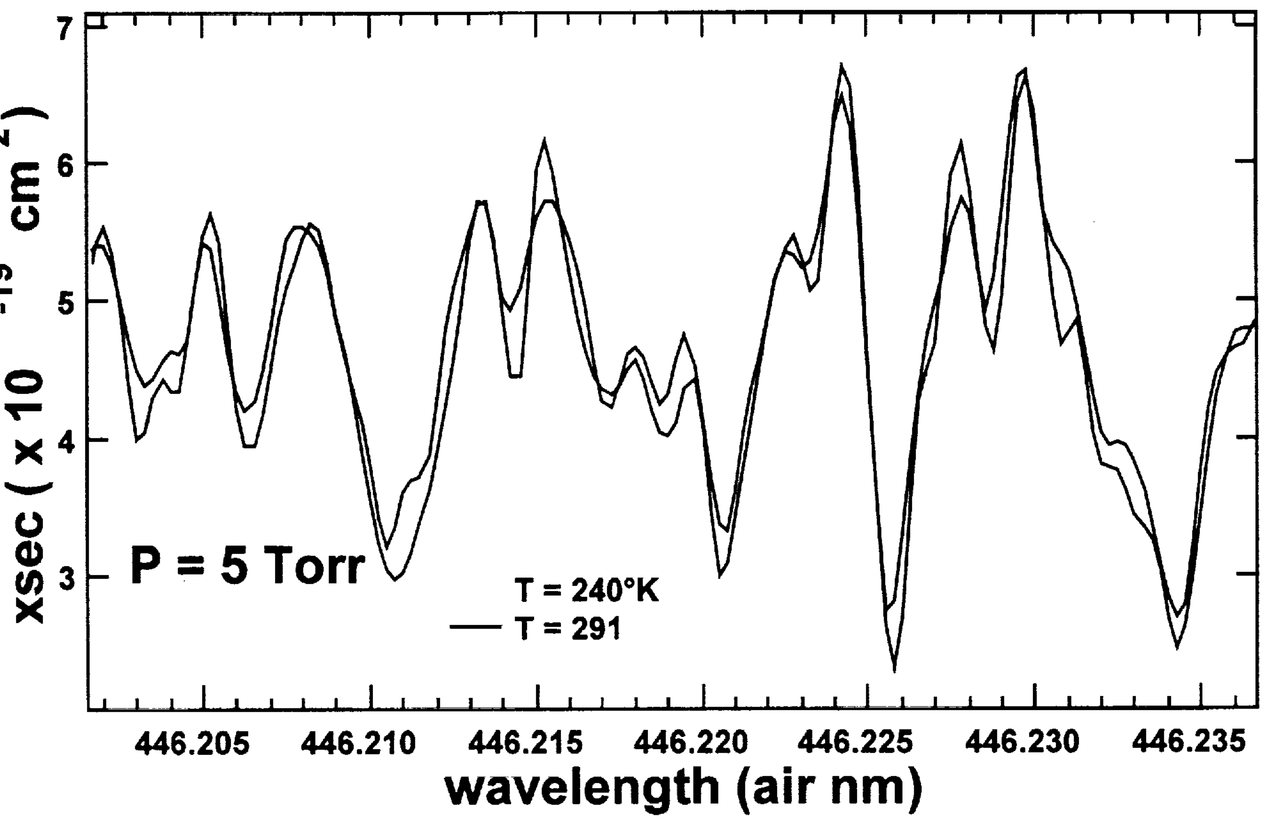


Figure 2. The temperature dependent structure of NO_2 at 240 and 291°K at high spectral resolution (from Harder,Brault, Johnston and Mount, 1997)

Figure 3 shows the data from Figure 2 smeared to 1 nm spectral resolution and ratioed. The differences are not trivial and will vary with the actual atmospheric temperature relative to whatever temperature is chosen for the data reduction, which means that the CHyMERA data analysis is going to have a problem with temperature dependent NO_2 structure from the cold stratosphere to the warmer troposphere, all of which is in the same column of NO_2. The stratospheric layer at 27 km needs to be reduced at lower temperature than the warmer temperature data more characteristic of the planetary boundary layer and/or lower troposphere. The problem will come from crossing spatially from one region characterized by some mixture of strat/trop temperature structure to a different spatial region with a different structure which will modulate the ratio of the wavelength pair. An average tropospheric temperature will be below room temperature, but getting a good number that will be some average of the data is going to be difficult. Attempts have been made to use the different structure to work on both regions simultaneously, but there is usually not enough information in the data to do this very successfully. A good fit is always obtained because there are too many degrees of freedom in the algorithm. We need to carefully consider the effects of temperature dependence in reducing the data. It will be doubly difficult with only wavelength pairs and the lack of substantial spectral information. The linear filter may solve some of the problems since it carries a lot of information. The 5-10% change over the 55°C shown here is extreme, but much larger than the small changes we are searching for (tenths of percent).

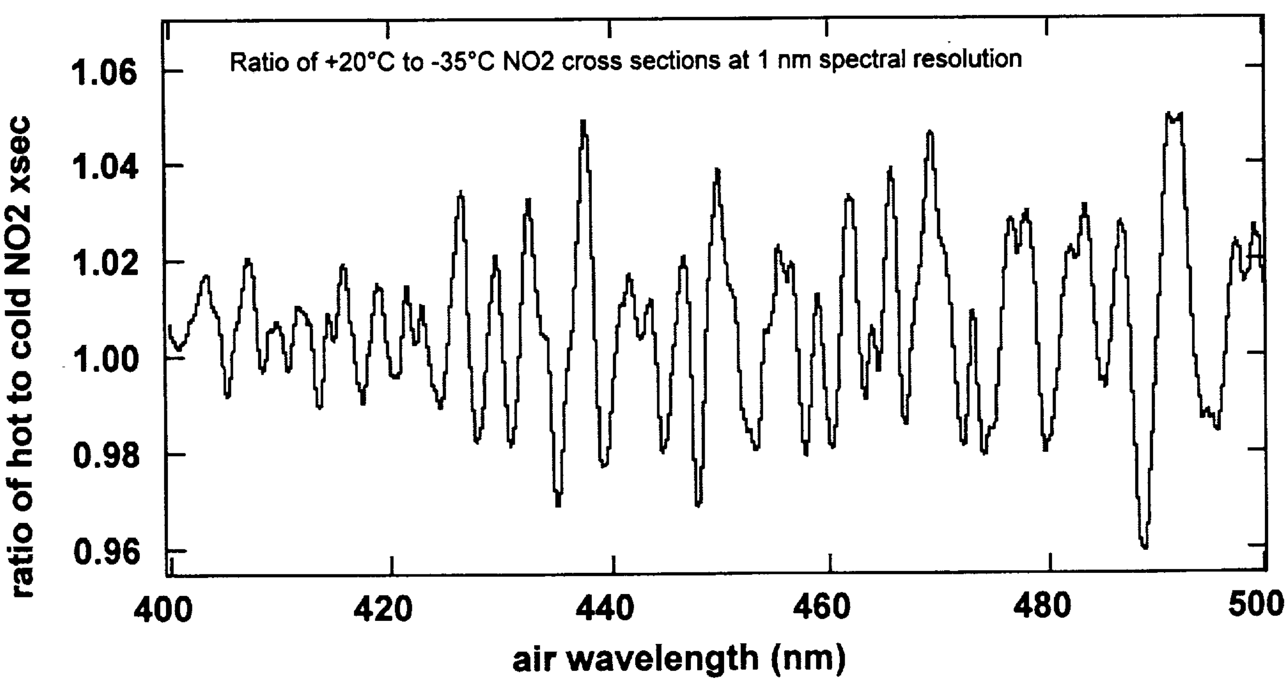


Figure 3. Ratio of +20 to -35°C NO_2 cross sections at 1 nm spectral resolution. This is perhaps a little extreme at 55°K temperature difference, but very instructive nonetheless.

We need to assess the effect of NO_2 temperature on data reduction for the wavelength pairs we choose. +20°C to -35°C is too big a temperature range, but with may not be too far off for actual ground level NO_2 in urban areas to real stratospheric temperature. For background troposphere, we would probably use a smaller number. Eric and I are using 240°K right now as an average tropospheric value - that is probably too low.

2. Compare 1 nm and 2 nm resolutions to see how much is lost by going to the 2 nm linear variable filter from 1 nm filters using wavelength pairs.

Figures 4 - 7 show NO_2 cross sections at 238°K as measured at 0.003 nm resolution with a wavelength scale accuracy of about 1 part in 10^7. These measurements were taken by Harder, Brault, Johnston and Mount (J. Geophys. Res., 1997, 102, 3861, 1997) on the FTS at Kitt Peak National Observatory. The cross sections have an absolute accuracy of 4%. Figure 1 shows the entire measured spectrum.

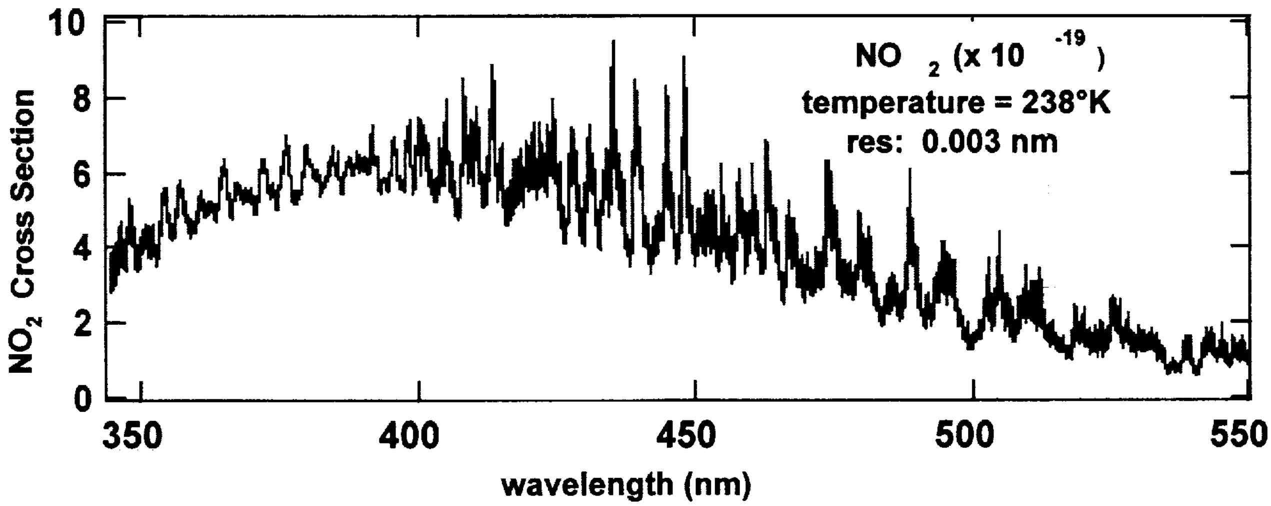


Figure 4. NO_2 cross sections as measured by Harder, Brault, Johnston and Mount (JGR , 1997). Resolution is 0.003 nm, air wavelength scale accurate to < 1 part in 10^7.

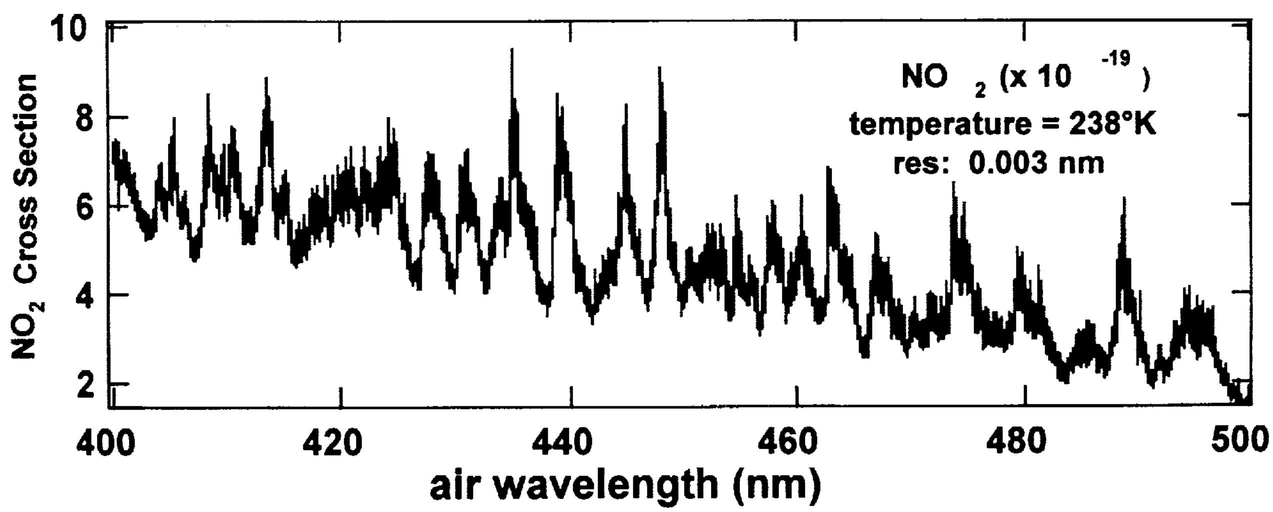


Figure 5. Main spectral region of interest.

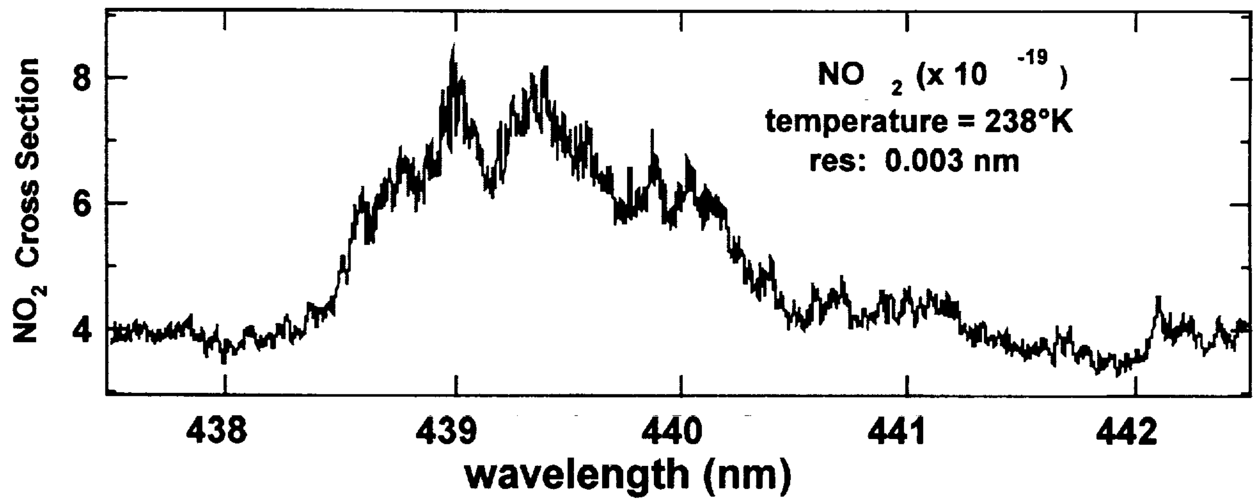


Figure 6. High resolution spectrum near the pair 439/442, a standard pair for NO_2 measurement, showing the spectral structure.

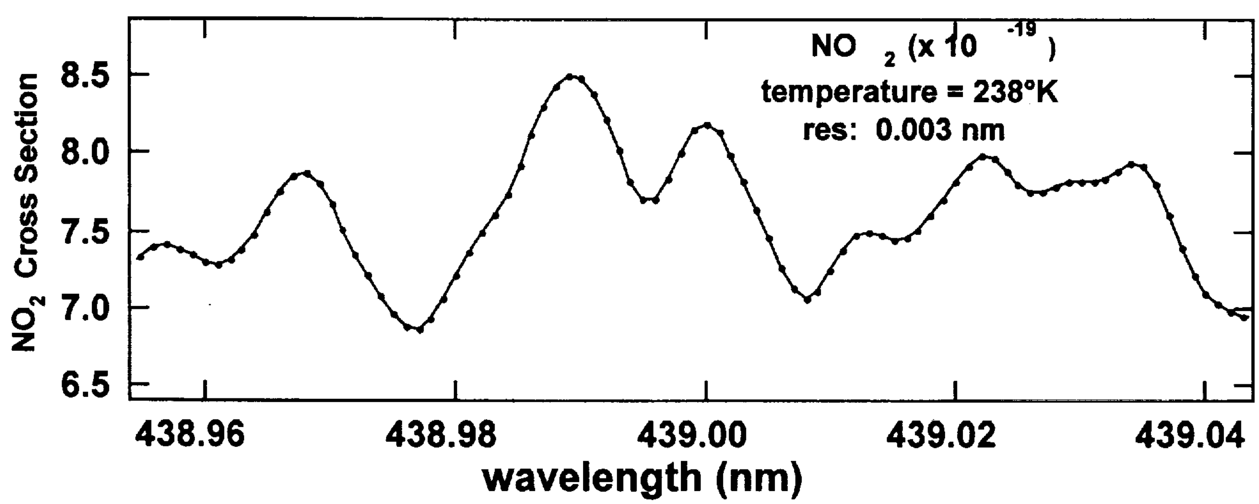


Figure 7. The spectral region right at the 439 nm peak showing the spectral structure as well as the sampling interval for the data used in this analysis (the data is oversampled). Note the virtually nonexistent noise on this data.

The NO_2 cross sections were smeared with 1 nm and 2 nm FWHM Gaussians. Figure 8 shows this for the region of interest, 400 -500 nm. Figure 9 shows the spectrum smeared to 1 nm in the region of the 439/442 wavelength pair.

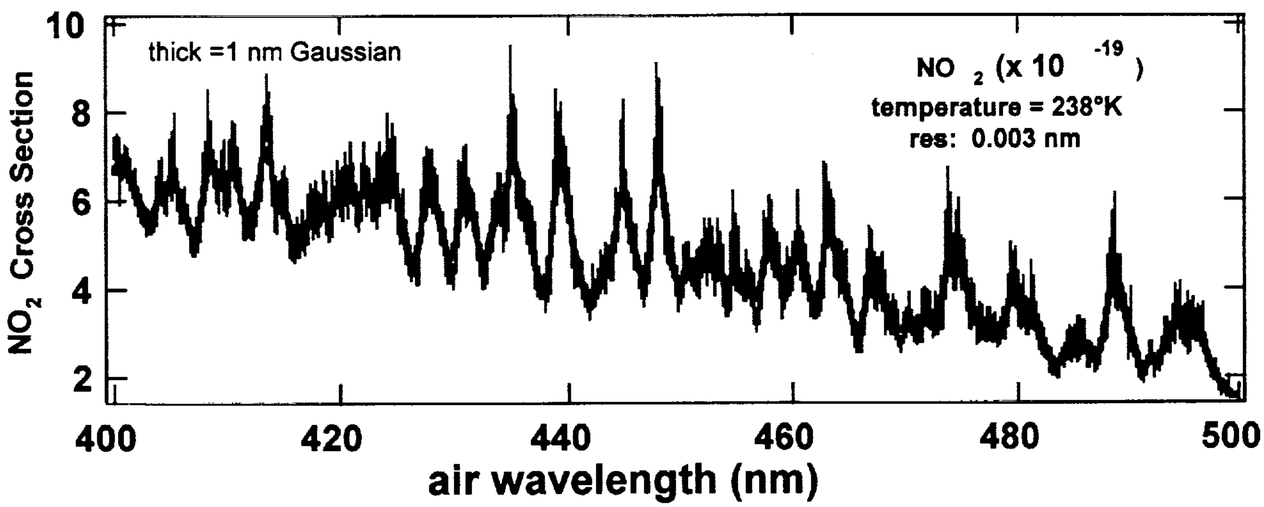


Figure 8. High resolution NO_2 cross sections and 1 nm Gaussian smeared NO_2 cross section.

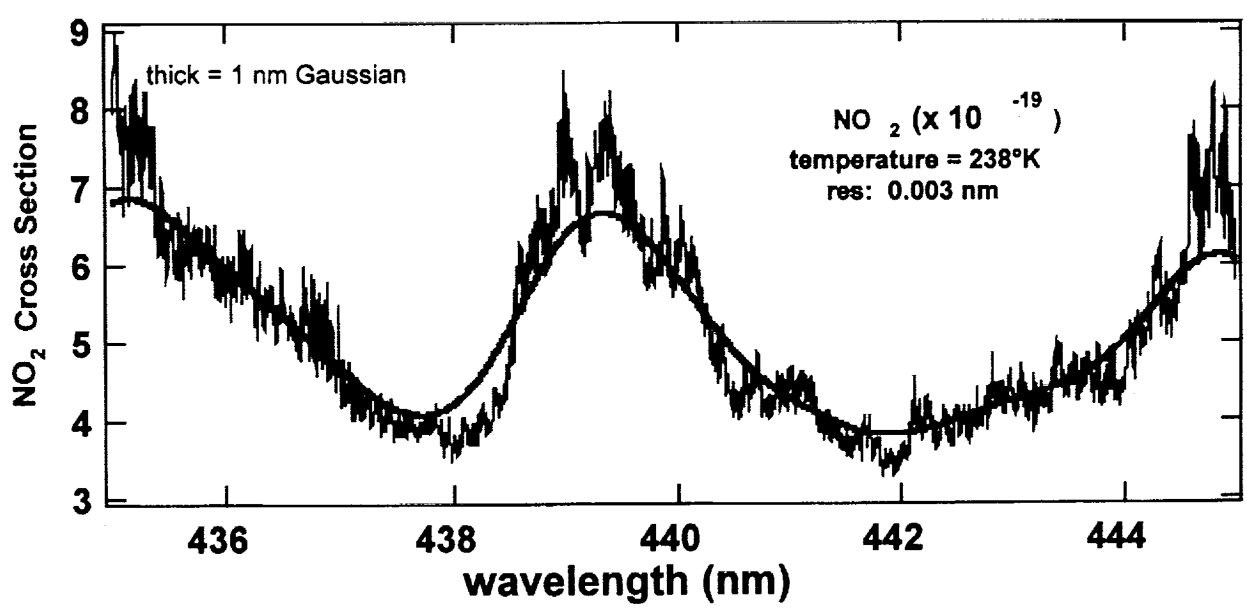


Figure 9. 1 nm NO_2 cross section at the 439/442 nm pair showing the low resolution structure.

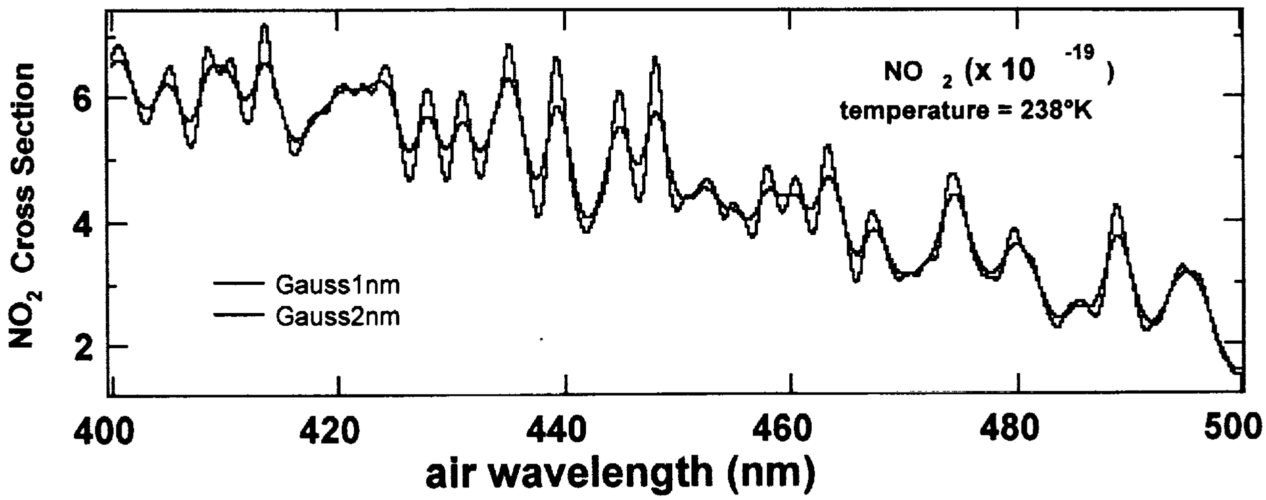


Figure 10. Low resolution Gaussian smeared spectra at 1 nm and 2 nm resolution, 400 -500 nm.

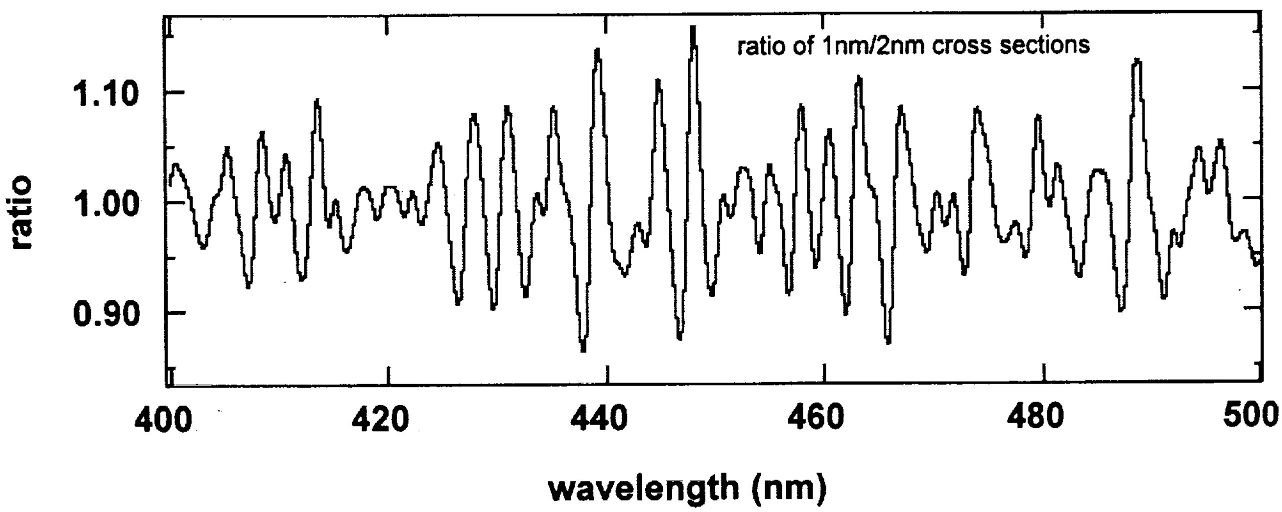


Figure 11. Ratio of 1 and 2 nm Gaussian smeared cross sections.

So just looking at the cross section ratios, it appears that the loss of NO_2 abundance recovery will be about 20% going from 1 nm to 2 nm spectral resolution, a fairly small number. If we choose spectral pairs not near the larger peaks in this ratio, the loss may be somewhat smaller. When we redo the analysis with actual sky data instead of just the cross sections, I would expect that the 2 nm smearing will make the Fraunhoffer and Ring spectra smoother and thus, the reduction will be a bit more robust. But there is no getting around the differential cross section differences.

Thus, the loss with the 2 nm filter will be small, on the order of 20% of the derived NO_2 sensitivity relative to the 1 nm data. This small loss at 2 nm makes the filter even more valuable. We should definitely implement it.

Conclusions:

(1) Clearly whatever temperature we choose, we cannot properly reduce the full column since the stratosphere is always cold and the troposphere always not nearly so cold. Using two temperatures for two layers probably gives too much leeway to the reduction algorithm so the solution is not unique. The percent differences between +20°C and -35°C are large at ±5% between peaks and adjacent valleys. We need to think hard about how this is going to affect the filter pair measurements as we scan over regions of varying vertical temperature structure.

(2) The linear filter is a must. The 2nm resolution is only about a 20% loss relative to 1nm.

Action items:

(1) Don should give us the length of the filter in the dispersion direction so we can calculate the filter spectral sampling
(2) Don should give us a take on nonlinearity of the filter dispersion with wavelength (i.e. is it linear or nonlinear; if nonlinear, is it nonlinear in a predictable way, or does it just wander around due to impurities and imperfections in the filter glass)
(3) How are we going to measure dispersion linearity and constancy of the filter bandwidth? [solar spectrum from scattered light]
(4) We need to discuss and assess the effects of temperature dependent cross sections on the tropospheric analysis as the spatial vertical temperature structure changes - this could be a big effect.
(5) Does the satellite velocity screw up the wavelength pairs due to Doppler shift?

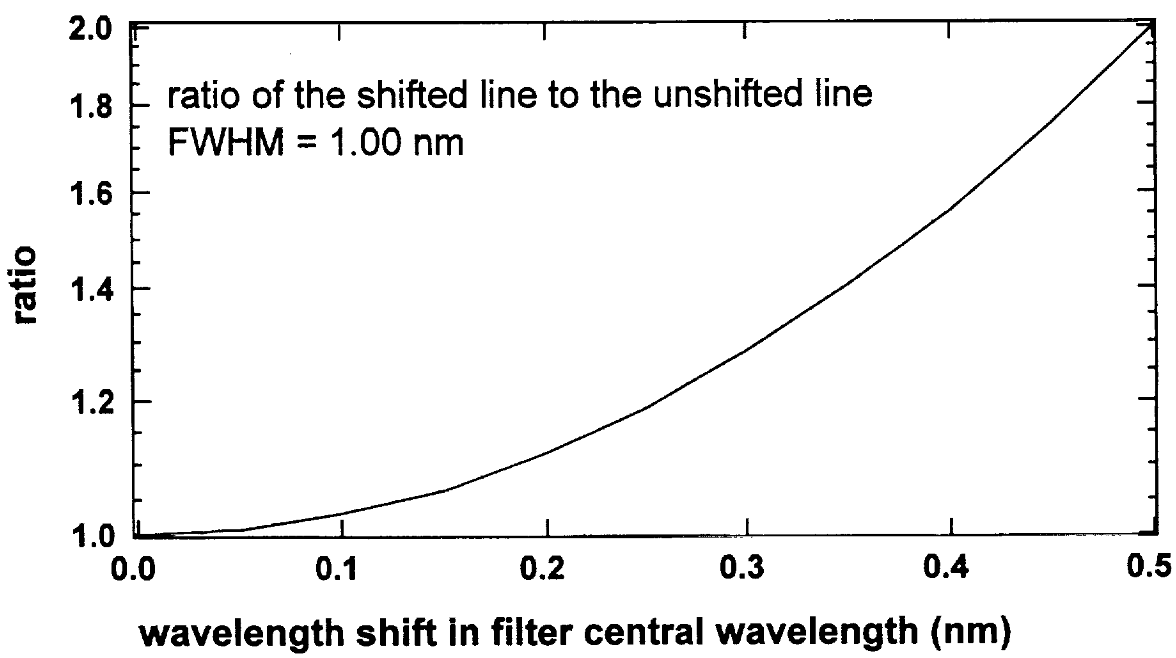
CHyMERA Filter Calculations
G.H. Mount
25 February 1999

Response to action items from the 11-12 February meeting:

3. Specification of central wavelength error for the filters.

Specification of the central wavelength error of the filters is very important. Barr will not succeed in centering them exactly, so we will need to give them a specification. As a first order cut at answering this question, I did some simple experiments with Gaussian shaped filters and came up with the following graph.

The simple method used was to generate a Gaussian of FWHM 1.00 nm and then to shift it by various amounts and see what the ratio of the properly centered filter to the shifted filter was at the specified central wavelength. Although this first cut does not use the actual reflected solar spectrum, Ring effect, and all, and it assumes the NO_2 cross section (convolved) lines are about 1 nm FWHM and Gaussian shaped (very good approximation), I don't think the result will be much different. In order to properly apply the real solar spectrum, Ring, etc., we would need to know which pairs we are going to use as the exact amount of inaccuracy will depend on an actual retrieval. For example, if the NO_2 line is in on a solar line wing, it may respond differently than if it is in a valley. Solar line widths are narrow (80 mA or so), so no matter where the NO_2 lines are located, things are not easy. And we don't know the filter wavelengths at this time anyway. So this simple analysis will give us a quick look at required accuracies. Note that the graph below is for a single wavelength, not a pair. Remember that the filters in the wavelength pair could shift in opposite directions, and the ratio curve is nonlinear.



Since we will know what the central wavelength of each filter is after they are manufactured, the ratio does not give an error in derived NO_2. Rather it tells us how much differential cross section (sensitivity) will be lost if the filter is made at the edge of the specified wavelength interval. For example, if we take a 20% loss of sensitivity as the maximum amount we can have, then about

0.13 nm is an acceptable shift in a single filter. A specification of ±0.1 nm would give a sensitivity loss of about 12%. The curve rises steeply as you move off the center wavelength, so a tenth nm seems about right to me.

Action Item:
Don, can Barr do ±0.1 nm ?

CHyMERA NO_2 Pair Calculations
G.H. Mount
12 March 1999
Very Preliminary (to be redone)

I have begun looking at the wavelength pair problem and wanted to send out a quick look data set. To begin, I just started with the sets that Eric found:

Group 4: 426.6 [426.48]	431.1 [430.98]	438.0 [437.88]	439.4 [439.28]
Group 6: 431.1 [430.98]	432.6 [432.48]	438.0 [437.88]	439.4 [439.28]
Group 10: 432.6 [432.48]	438.0 [438.88]	439.4 [439.28]	450.0 [449.87]

with [ ] giving air wavelengths from Scott. However, these wavelengths were derived from approximate wavelengths Eric used from GOME (Eric's had only one figure after the decimal and Scott converted from those). I have taken the Harder, Brault, Johnston and Mount NO_2 data set which has a wavelength accuracy better than 1 part in 10^7, and derived the exact wavelengths (in air) for Eric's wavelengths. Thus, the final filter list, *assuming* we use groups 4, 6, and 10, is:

426.32, 430.97, 432.53, 437.72, 439.32, and 449.90 nm [air].

Figure 1 below shows the peaks and valleys in Eric's groups 4, 6, and 10.

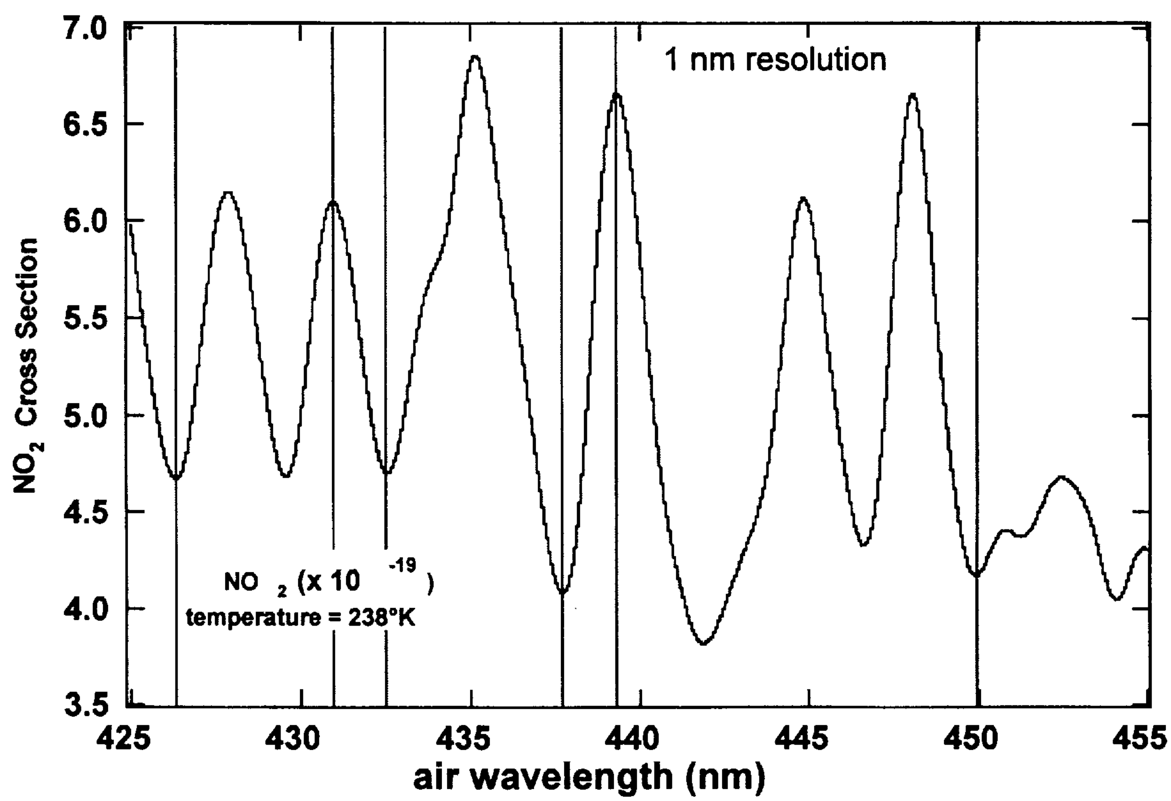


Figure 1. NO_2 cross section at 1 nm resolution in air with groups 4, 6, and 10 marked.

Instead of using GOME data, I decided to try a different tack using Fritz Peak zenith sky data to check the quality of fit with these 6 wavelengths. So the data I used were taken with our double 3/8 m diode array spectrograph which can measure easily to 0.02% absorption levels (see Figure 1 in my report of 23 February). I reduced the zenith sky data for a day in 1995 (4 April) using the complete nonlinear least squares algorithm that we developed at NOAA as well as a constant fit, slope fit, Ring spectrum fit, ozone fit, and polarization fit - basically everything except water and NO_2. It has been used for some years and works very well. This produced NO_2 slant column abundance against solar zenith angle (time). Integration times were a few minutes for each data point. I then took the following pair ratios to derive independent NO_2 slant abundances at several solar zenith angles using data from which everything had been removed except NO_2.

449.90/439.32
439.32/437.72
439.32/432.53
432.53/430.97
430.97/437.72
430.97/439.32
430.97/426.32
426.32/439.32

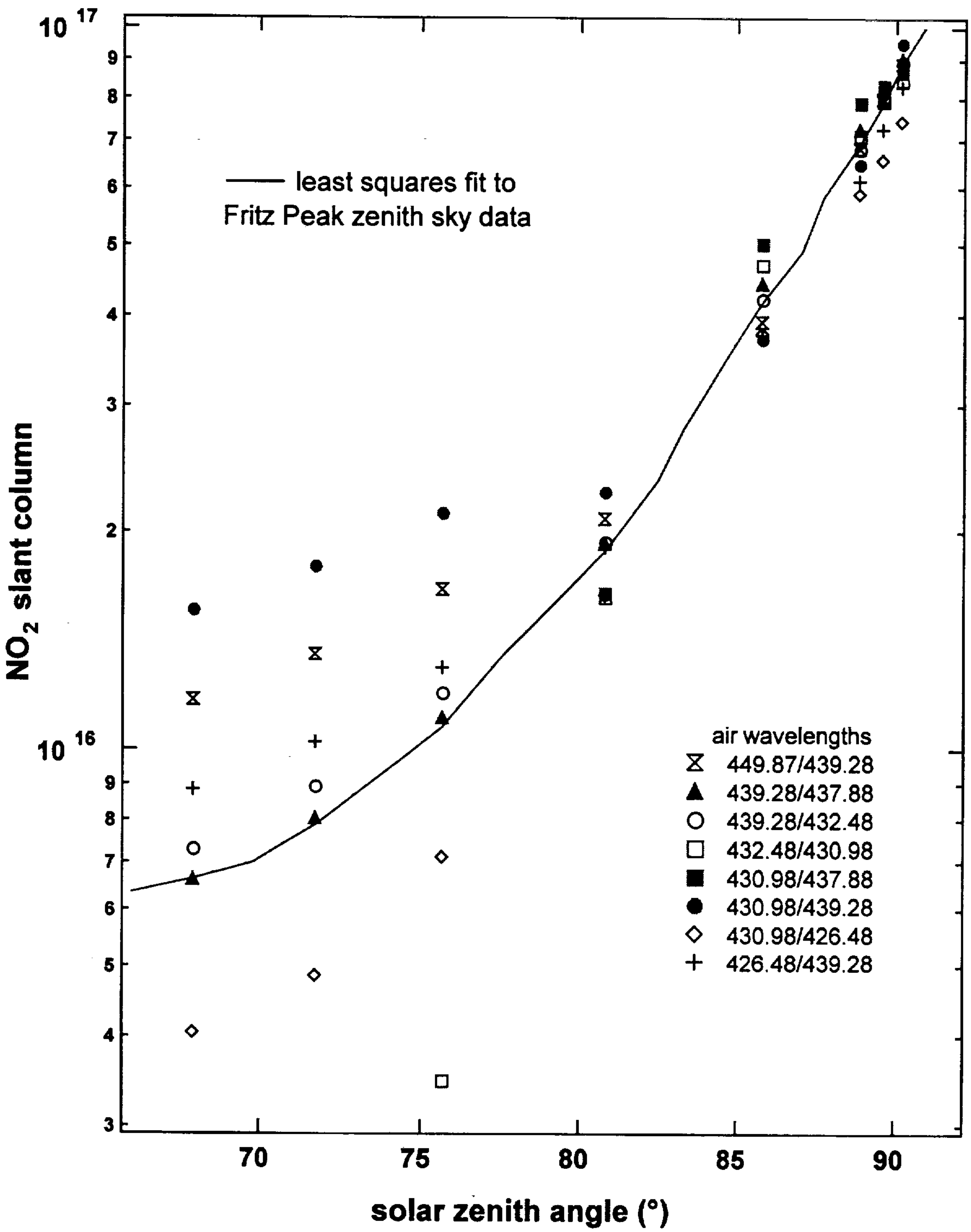
This left sky data with a very obvious NO_2 spectrum in it to work from, and from which Ring and other things had been removed. These ratios produced the NO_2 slant columns shown in the following two figures as symbols, each one corresponding to a different pair ratio. The solid line is the data reduced using the full spectrum with the nonlinear least squares. From this analysis, it is clear that the best pairs are:

439.32/437.72
439.32/432.53

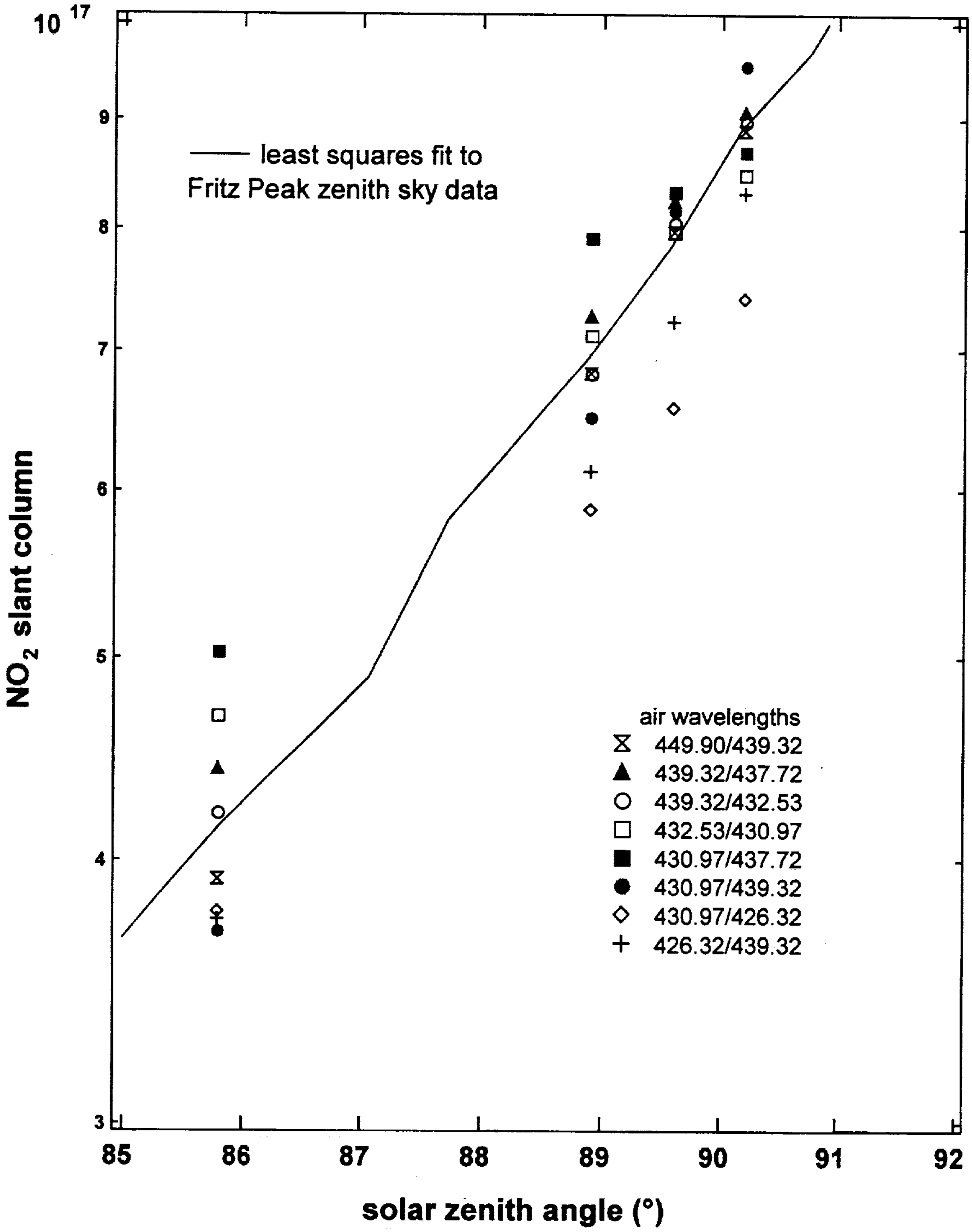
The other ones do not fit well, in particular the 430.97/426.32, 430.97/437.72, and 432.53/430.97 pairs.

These results are somewhat discouraging, and I plan to redo the analysis and see what I get. I would think that the pairs should work equally well on zenith sky data as GOME data, but perhaps some one can think of a reason why it would mess up (remember that the Ring spectrum was taken into account). The errors are quite large in some cases.

Let me know what you think.



least squares fit to Fritz Peak zenith sky data
air wavelengths
449.87/439.28
439.28/437.88
439.28/432.48
432.48/430.98
430.98/437.88
430.98/439.28
430.98/426.48
426.48/439.28
NO_2 slant column
solar zenith angle (°)
10 17
10 16
70
75
80
85
90



10^{17}
9
8
7
6
5
4
3
85
86
87
88
89
90
91
92
NO_2 slant column
solar zenith angle (°)
least squares fit to
Fritz Peak zenith sky data
air wavelengths
449.90/439.32
439.32/437.72
439.32/432.53
432.53/430.97
430.97/437.72
430.97/439.32
430.97/426.32
426.32/439.32

CHyMERA NO_2 Pair Calculations
G.H. Mount
24 March 1999

I have begun looking at the wavelength pair problem. To begin, I just started with the sets that Eric found:

Group 4:	426.6 [426.48]	431.1 [430.98]	438.0 [437.88]	439.4 [439.28]
Group 6:	431.1 [430.98]	432.6 [432.48]	438.0 [437.88]	439.4 [439.28]
Group 10:	432.6 [432.48]	438.0 [438.88]	439.4 [439.28]	450.0 [449.87]

with [ ] giving air wavelengths from Scott. These wavelengths were derived from the approximate wavelengths Eric used from GOME (Eric's had only one figure after the decimal and Scott converted from those). I have taken the Harder, Brault, Johnston and Mount NO_2 data set which has a wavelength accuracy better than 1 part in 10^7, and derived the exact wavelengths (in air) for Eric's wavelengths. Thus, the final filter list, *assuming* we use groups 4, 6, and 10, is:

426.32, 430.97, 432.53, 437.72, 439.32, and 449.90 nm [air].

Figure 1 below shows the peaks and valleys in spectral region 425 - 455 nm.

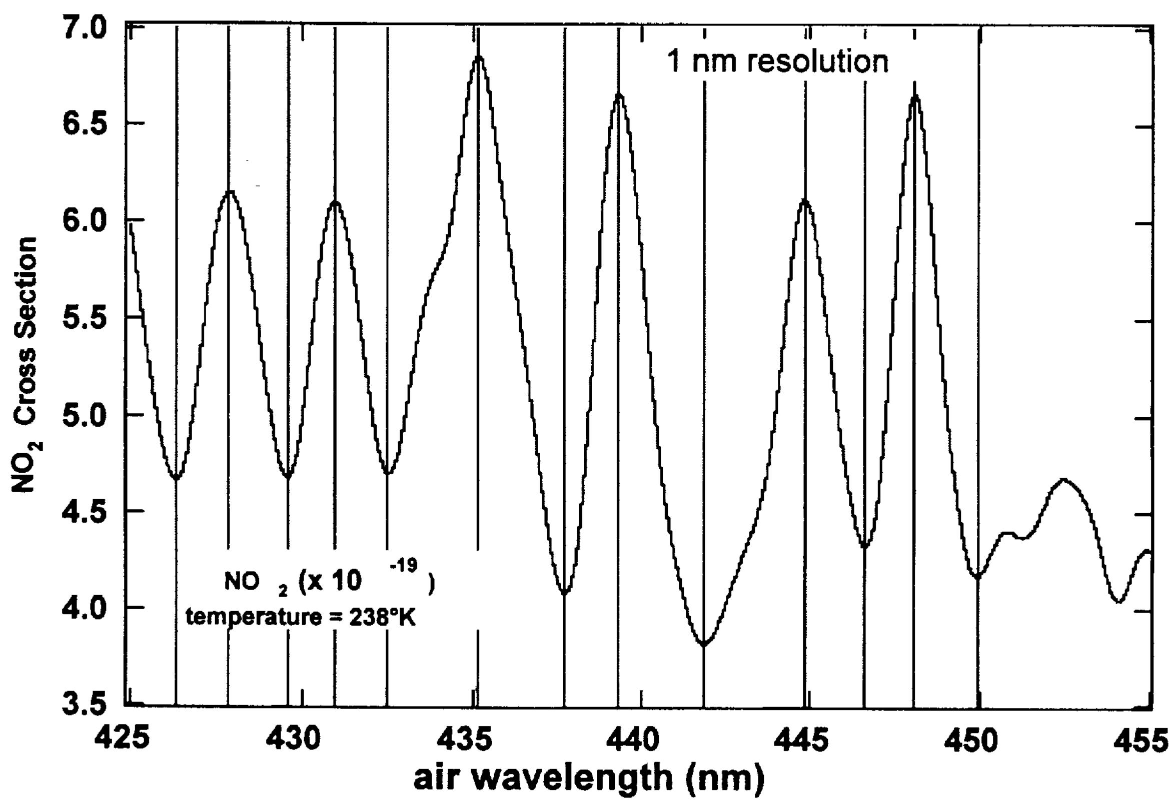


Figure 1. NO_2 cross section at 1 nm resolution in air 425 - 455 nm.

Instead of using GOME data, I decided to try a different tack using Fritz Peak zenith sky data to check the quality of fit with all the reasonable wavelength pairs in this spectral region. The data I used were taken with our double 3/8 m diode array spectrograph which can measure easily to 0.02% absorption levels (see Figure 1 in my report of 23 February). I reduced the zenith sky data for a day (with air pollution - so the column abundance against time was not smooth) in 1995 (4 April) using the complete nonlinear least squares algorithm that we developed at NOAA with a constant fit, slope fit, Ring spectrum fit, ozone fit, and polarization fit - basically everything except water and NO_2. It has been used for some years and works very well. This produced NO_2 slant column abundance against solar zenith angle (time). Integration times were a few minutes for each data point.

I then took Eric's wavelength pairs to derive independent NO_2 slant abundances at several solar zenith angles using data from which everything had been removed except NO_2. This left sky data with a very obvious NO_2 spectrum in it to work from, and from which Ring and other things had been removed. These ratios produced the NO_2 slant columns (symbols) shown in the following figure, each one corresponding to a different pair ratio. The solid line is the data reduced using the full spectrum with the nonlinear least squares, and which should be very accurate. The data from Eric's pairs is not very consistent. The best pairs appear to be numbers 2 and 3. I used a day with air pollution on purpose, so the curve would not be smooth, but would have jumps in it from dirty air containing NO_2 drifting over the instrument field of view. I thought this would provide a more stringent test. The next figure shows the ratio of the pair-derived NO_2 to the least squares-derived NO_2 plotted against the least squares derived NO_2, once again for Eric's wavelengths. This graph vividly illustrates the quality of the fit. Marked on the graph are the 1.00 perfect fit and the $\pm$10% and +20% lines for reference. The errors increase with decreasing derived NO_2 column abundance as expected. Only ratio number 2 stays within $\pm$10% over the range of measurements. I reduced pairs down to $4x10^{14}$ cm^{-2} inorder to see how good the retrieval would be at these low numbers. It will give us a good idea of how we will do at low abundances.

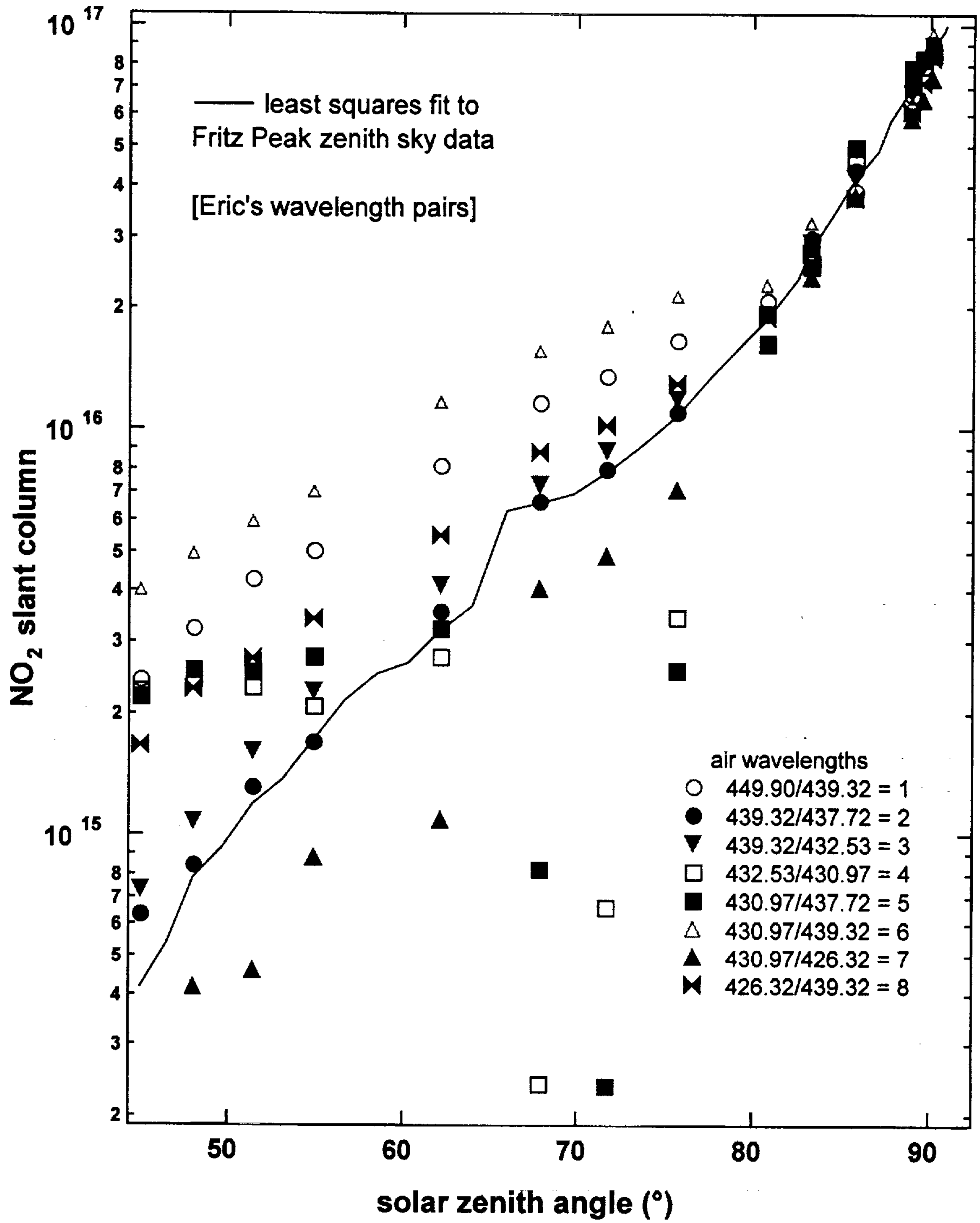


Figure 2. Slant column NO_2 derived from the least squares analysis (solid line) and from Eric's wavelength pairs (symbols) as a function of solar zenith angle (time) for 4 April 1995 at Fritz Peak Observatory, Colorado. Observations are of the zenith sky. Ring and all effects except NO_2 and water have been taken into account in the data used to compute the pair ratios and deduce NO_2. The numbers to the right of the pairs are the array numbers in my program. Slant column is not smooth due to air pollution (purposely chosen).

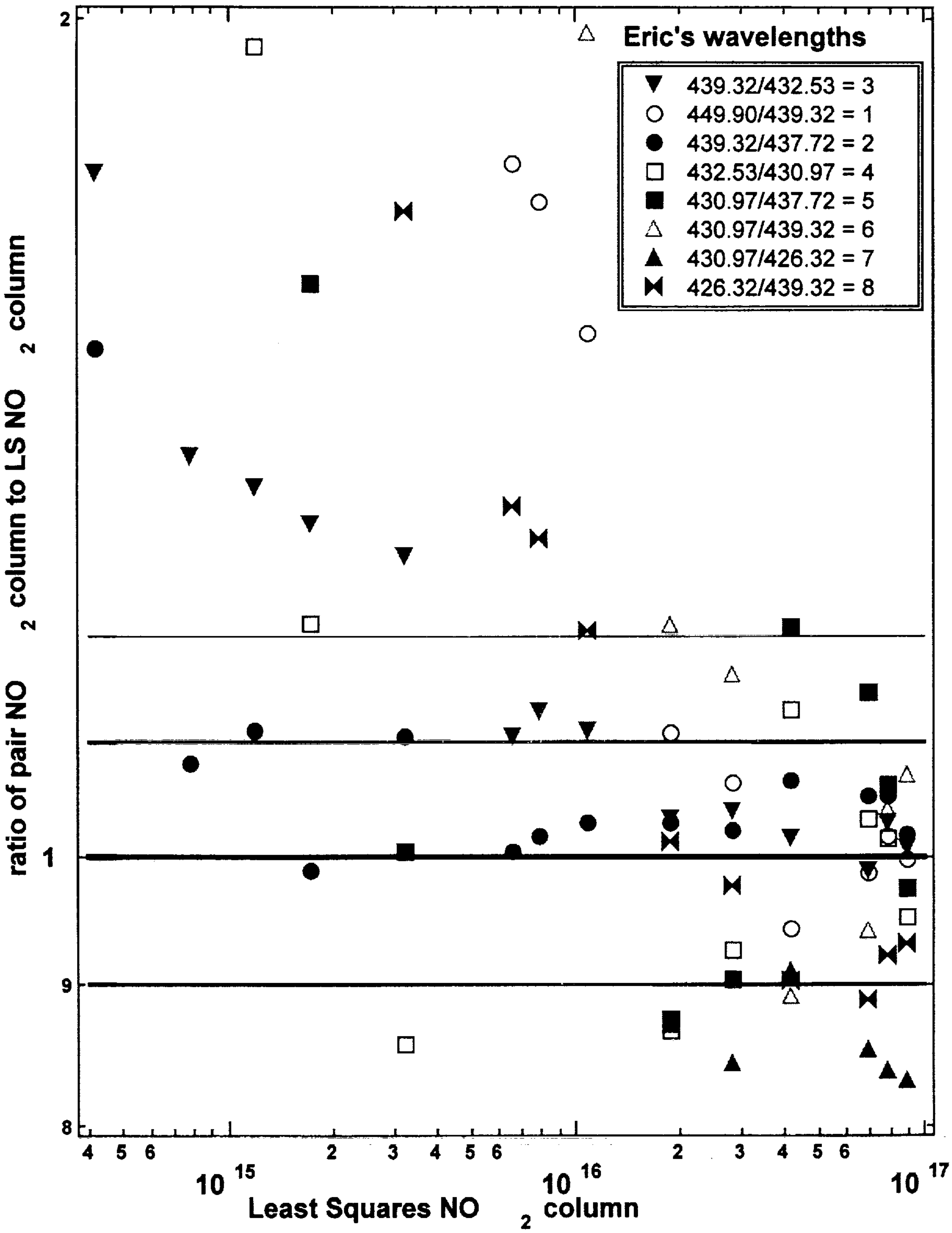


Figure 3. Ratio of pair-derived NO_2 to least squares-derived NO_2 plotted against least squares-derived NO_2 for Eric's wavelength pairs. Marked are the 1.00 perfect fit, and $\pm$10% and +20% lines.

The next thing I did was to take all the reasonable wavelength pairs (did not use up to up or down to down pairs, only up to down) and redo the analysis. This produced the data shown in the next figure.

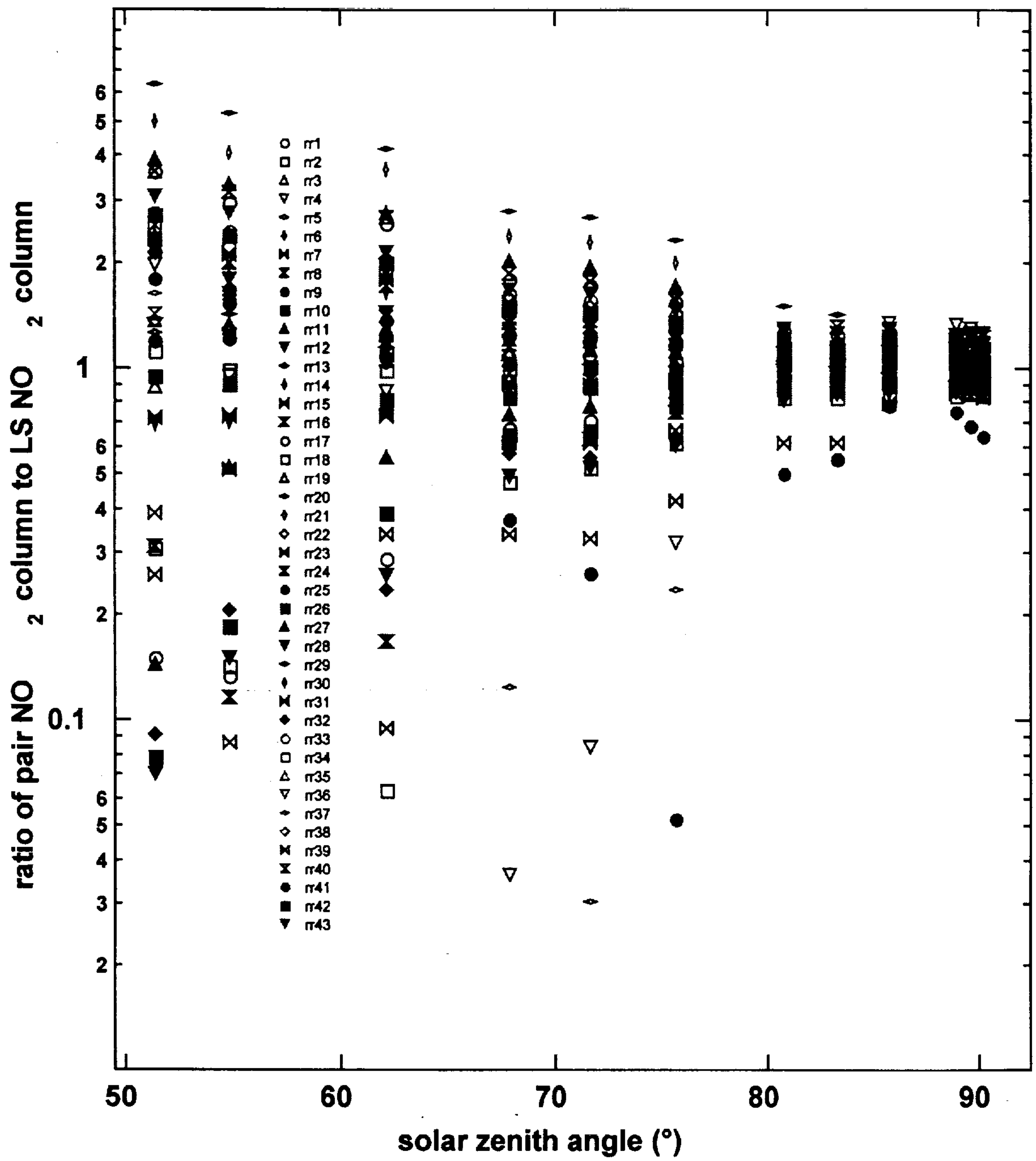


Figure 4. Forty three pairs (including Eric's) used from spectral range 425 - 455 nm as shown in Figure 1. Ratio of pair-derived NO_2 column to least squares-derived NO_2 column plotted against solar zenith angle.

There is a lot of variation about the perfect fit (1.00) with peak to peak variation as high as a factor of 5 high and over a factor of 20 low. This is not surprising since no selection factors were applied to the data. The next figure shows the same data plotted against least squares-derived NO_2.

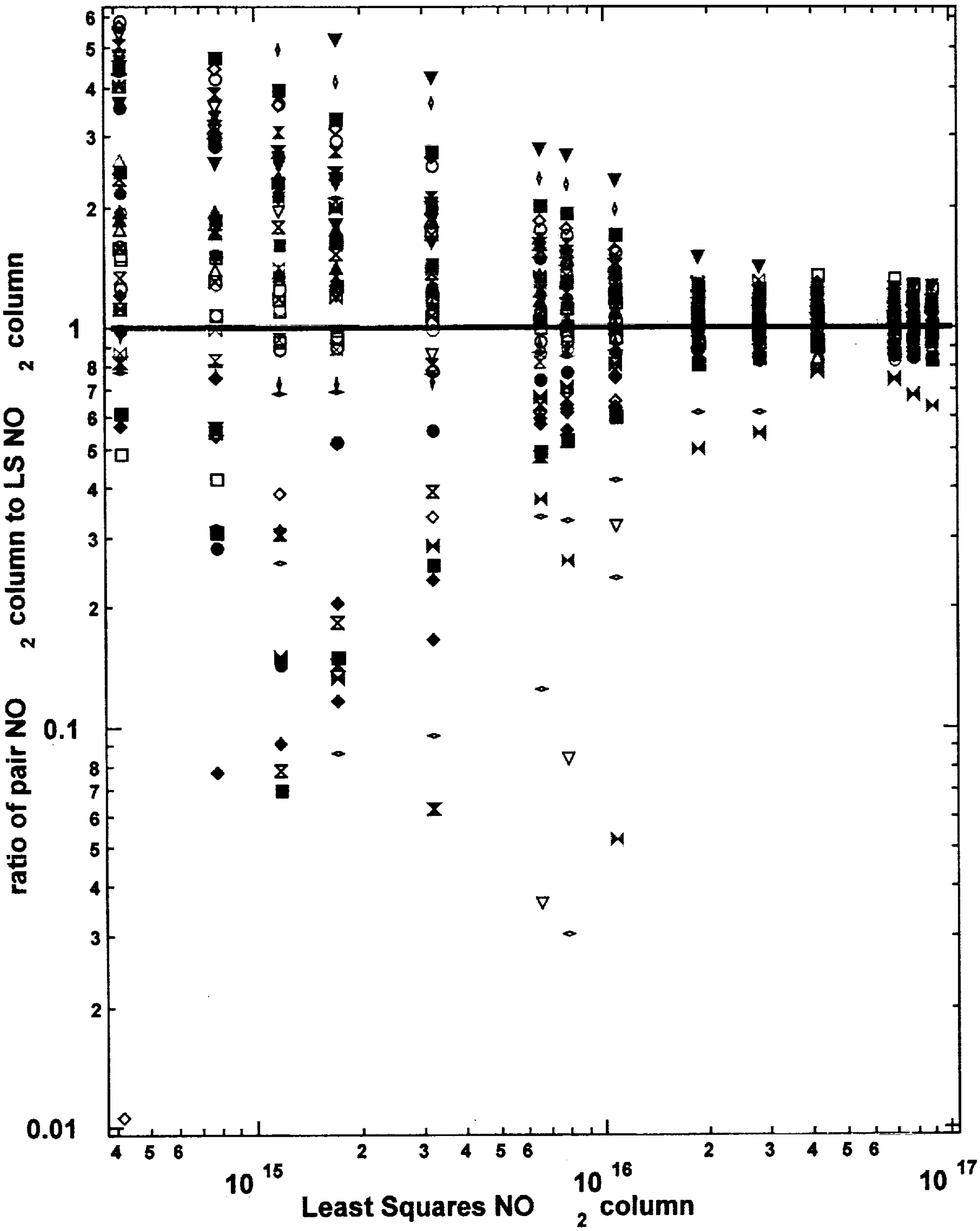


Figure 5. Same data as figure 4 plotted against least squares-derived column NO_2.

I reduced the data down to $4x10^{14}$ to show how good the accuracy is at these low column values. Some of the pairs are still good here. The next figure shows selected wavelength pairs where the selection has been chosen to be in the $\pm 10\%$ band about a perfect fit down to $5x10^{15}$.

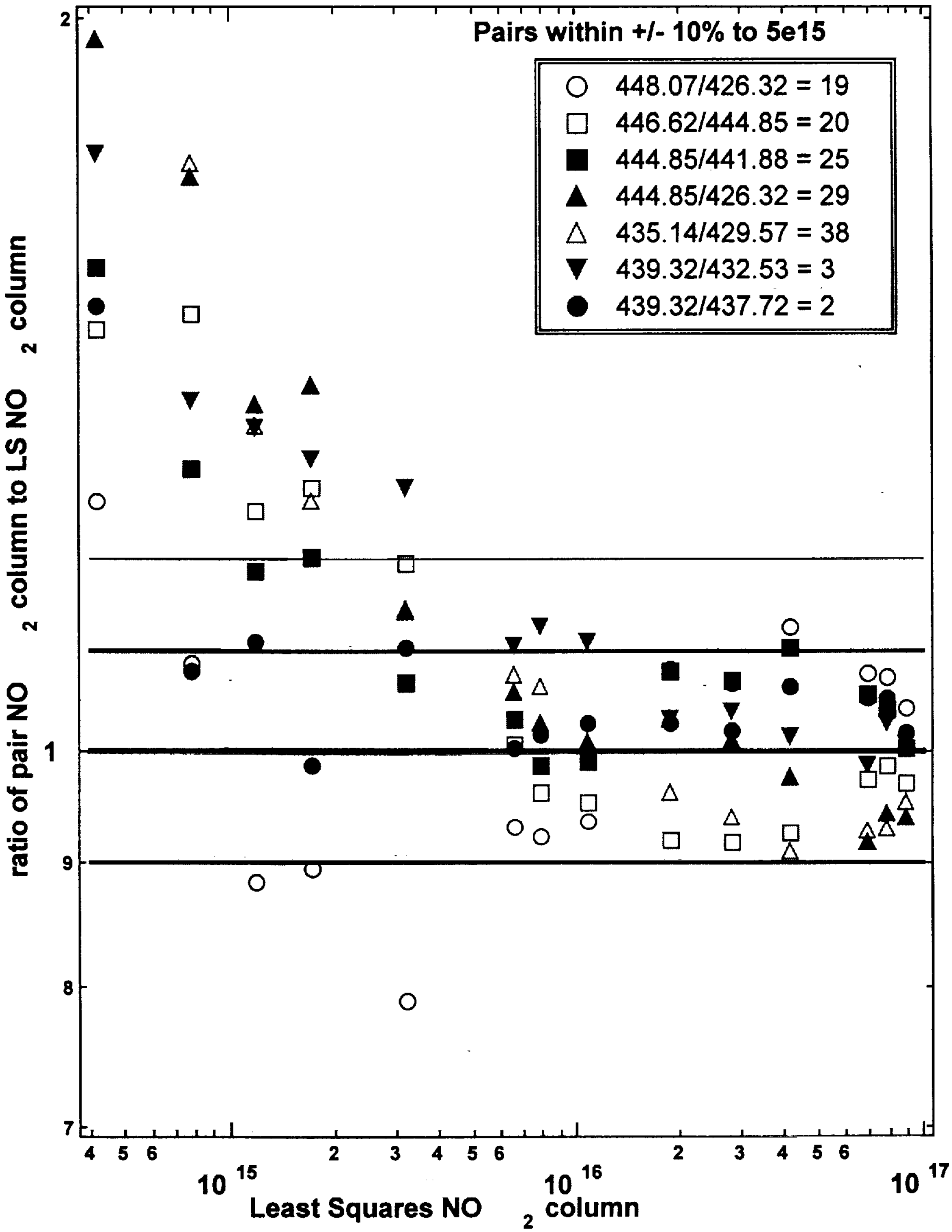


Figure 6. Same data, but selected to fit into the $\pm 10\%$ band about a perfect fit above $5x10^{15}$.

There are still large outlyers below $5x10^{15}$. The next graph shows the same data, but with pairs selected to fit within $\pm 10\%$ down to $3x10^{15}$.

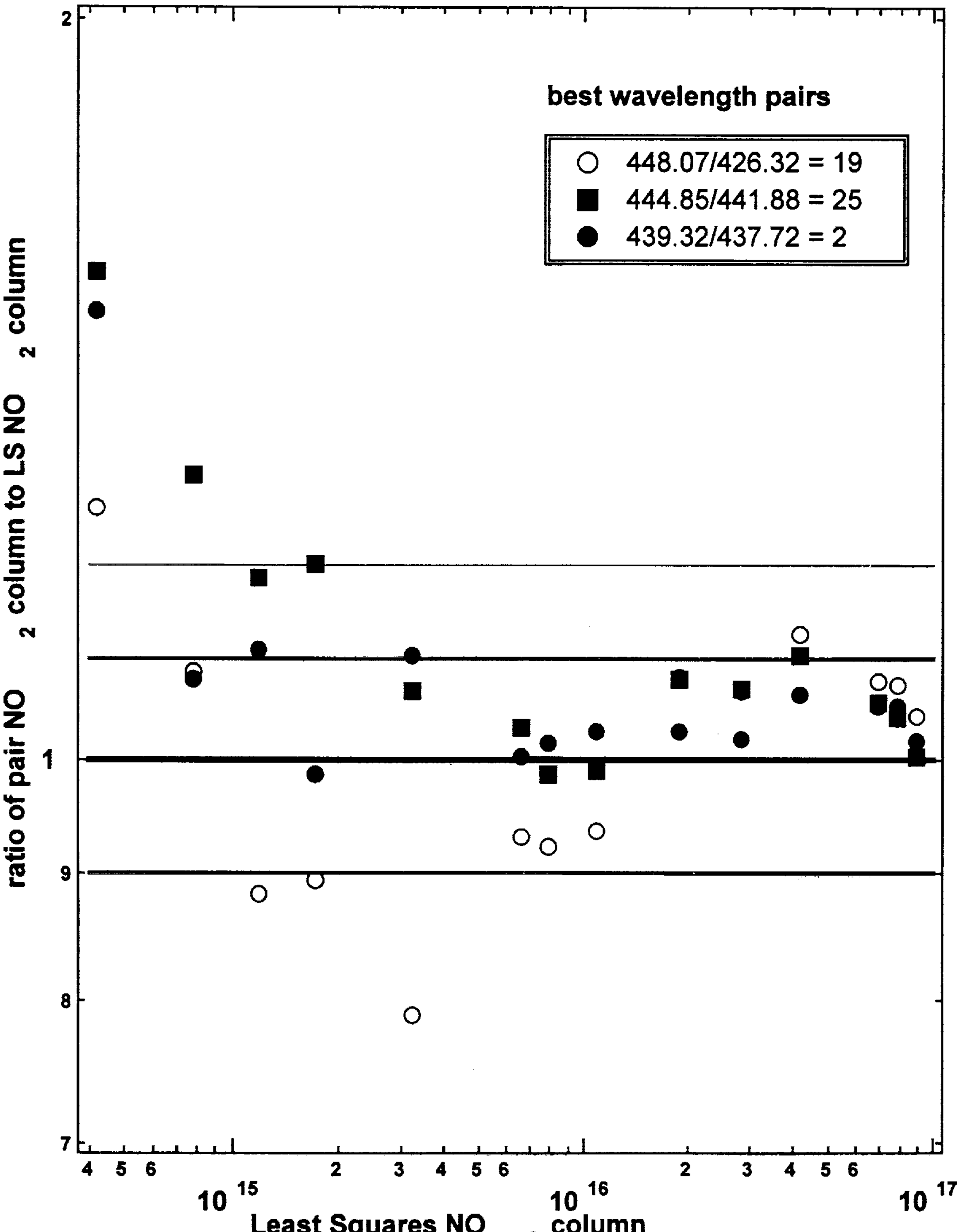


Figure 7. The same data, but selected to fit within $\pm 10\%$ of a perfect fit to the least squares to 3 $x10^{15}$.

This final graph shows that the best fits are obtained with one of Eric's pairs, but the other good pairs are different, and one is quite surprising (19) given the wavelength separation and the usual problems with understanding slopes and things between separated lines.

Looking at this data, it is quite perturbing. I have ignored water, and Eric has worked with water. But I find the most of the pairs suggested by his analysis do not work well. On the bright side, it is amazing that pairs 2 and 25 fit within $\pm 10\%$ all the way to less than 1×10^{15} column; very encouraging for the pair idea. It is also interesting, as Eric found, that the usual wavelength pair used by people doing pair work, 439.32/441.88, does not work at all well in either this analysis or Eric's. The next figure shows this plot individually. The fit is not good.

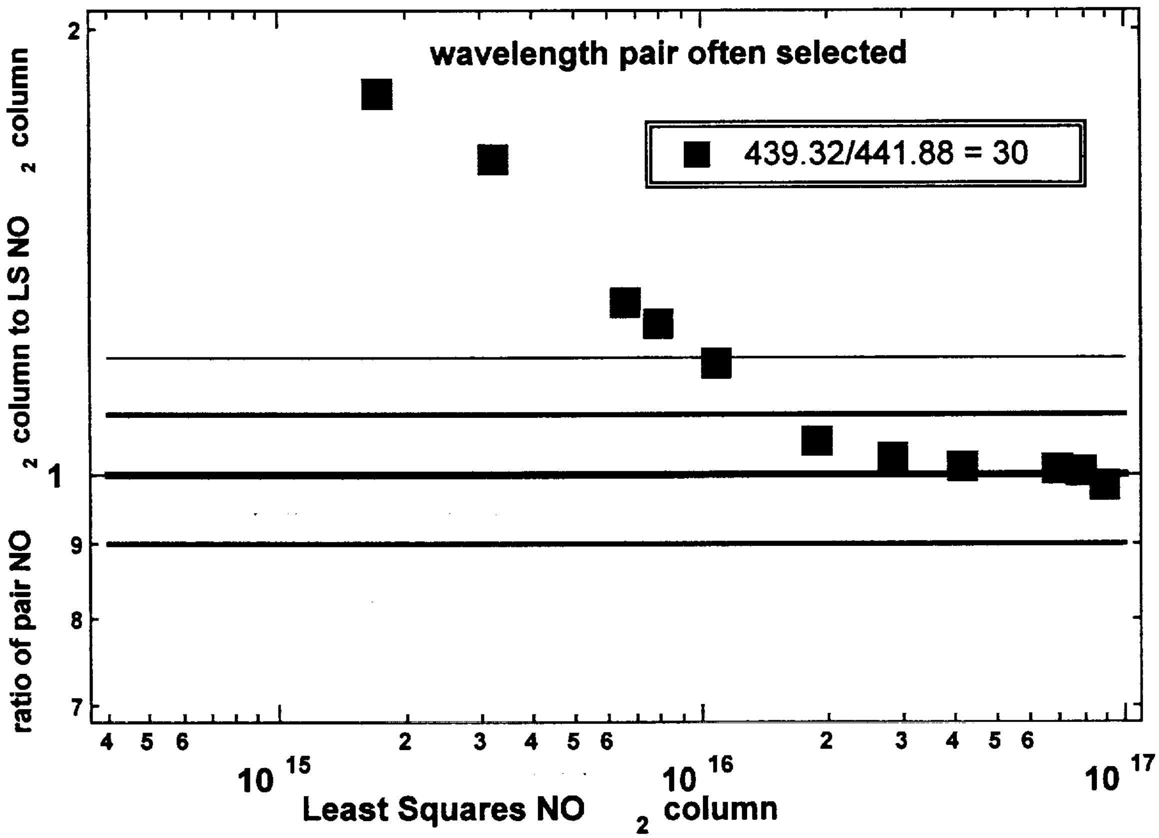


Figure 8. The fit for a wavelength pair often selected as best for pair analysis. Shown is the 1.00 perfect fit; $\pm 10\%$ and + 20%. The fit is terrible.

I need to repeat this analysis on another data set, and I need to spend some time thinking about all this. We need to better understand why Eric's wavelength pairs do not fit as well as I would have thought given the thoroughness of his analysis. Perhaps Eric could give his analysis of the pairs shown in Figure 7. And we need to choose a good null pair, one that goes through the analysis that Eric has performed on the NO_2 pairs, so we make an intelligent choice. I will procede to analyse another data set to see if these numbers hold up. I will also begin a shifting of wavelength centers for the pairs and do an error analysis.

Scott - when do you need a final set of filter wavelengths?? Thoughts from you all??????

CHyMERA NO_2 Pair Calculations
Effect of Shifts in Filter Bandpass on Derived NO_2
G.H. Mount
26 March 1999

Figure 1 below shows the peaks and valleys in spectral region 425 - 455 nm. These are the pairs that I have concentrated on studying.

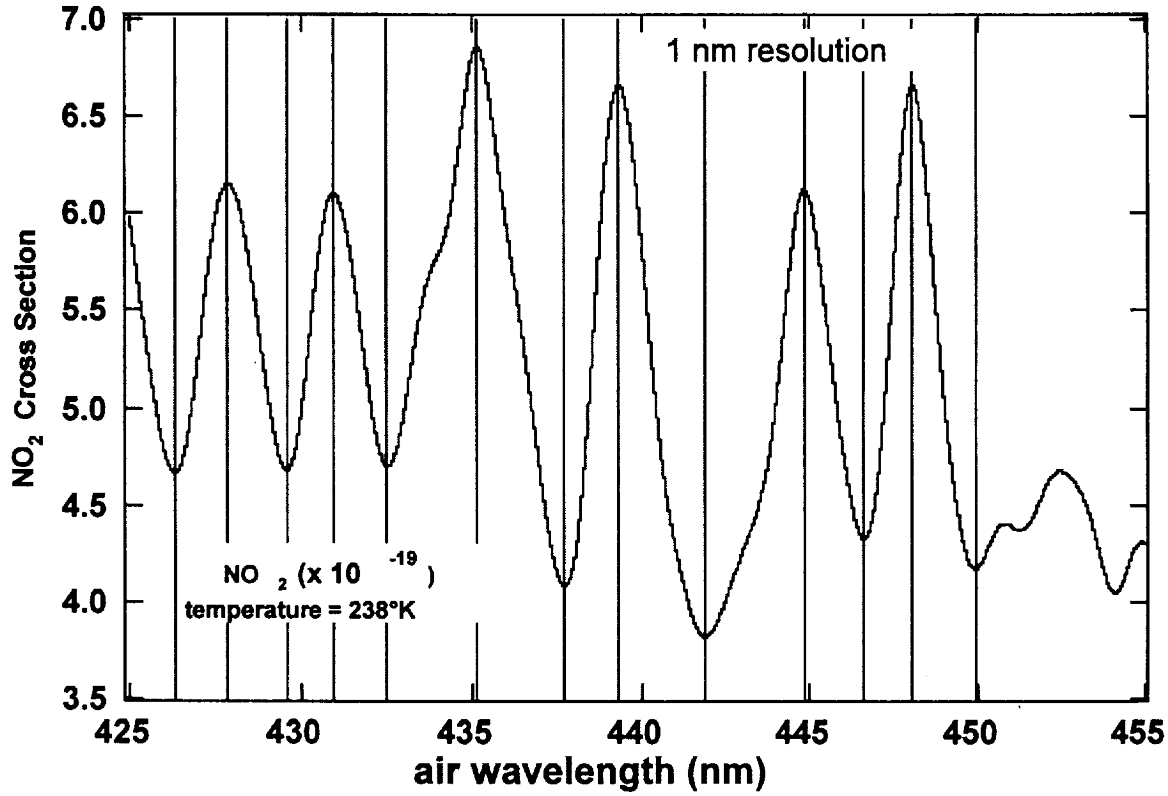
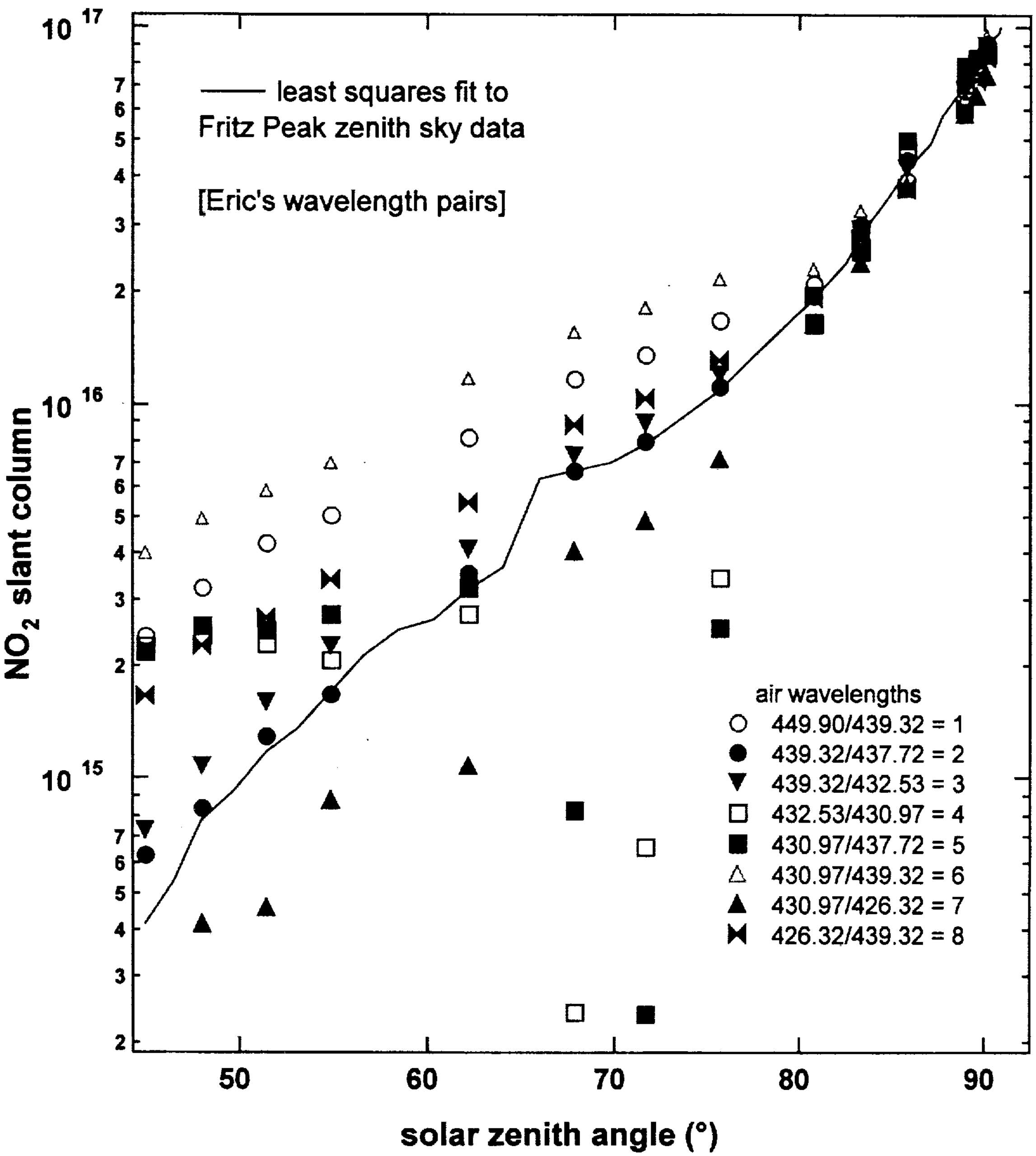


Figure 1. NO_2 cross section at 1 nm resolution in air 425 - 455 nm.

I used Fritz Peak zenith sky data to check the quality of fit with all the reasonable wavelength pairs in this spectral region. The data I used were taken with our double 3/8 m diode array spectrograph which can measure easily to 0.02% absorption levels (see Figure 1 in my report of 23 February). I reduced the zenith sky data for a day (with air pollution - so the column abundance against time was not smooth) in 1995 (4 April) using the complete nonlinear least squares algorithm that we developed at NOAA with a constant fit, slope fit, Ring spectrum fit, ozone fit, and polarization fit - basically everything except water and NO_2. It has been used for some years and works very well. This produced NO_2 slant column abundance against solar zenith angle (time). Integration times were a few minutes for each data point.

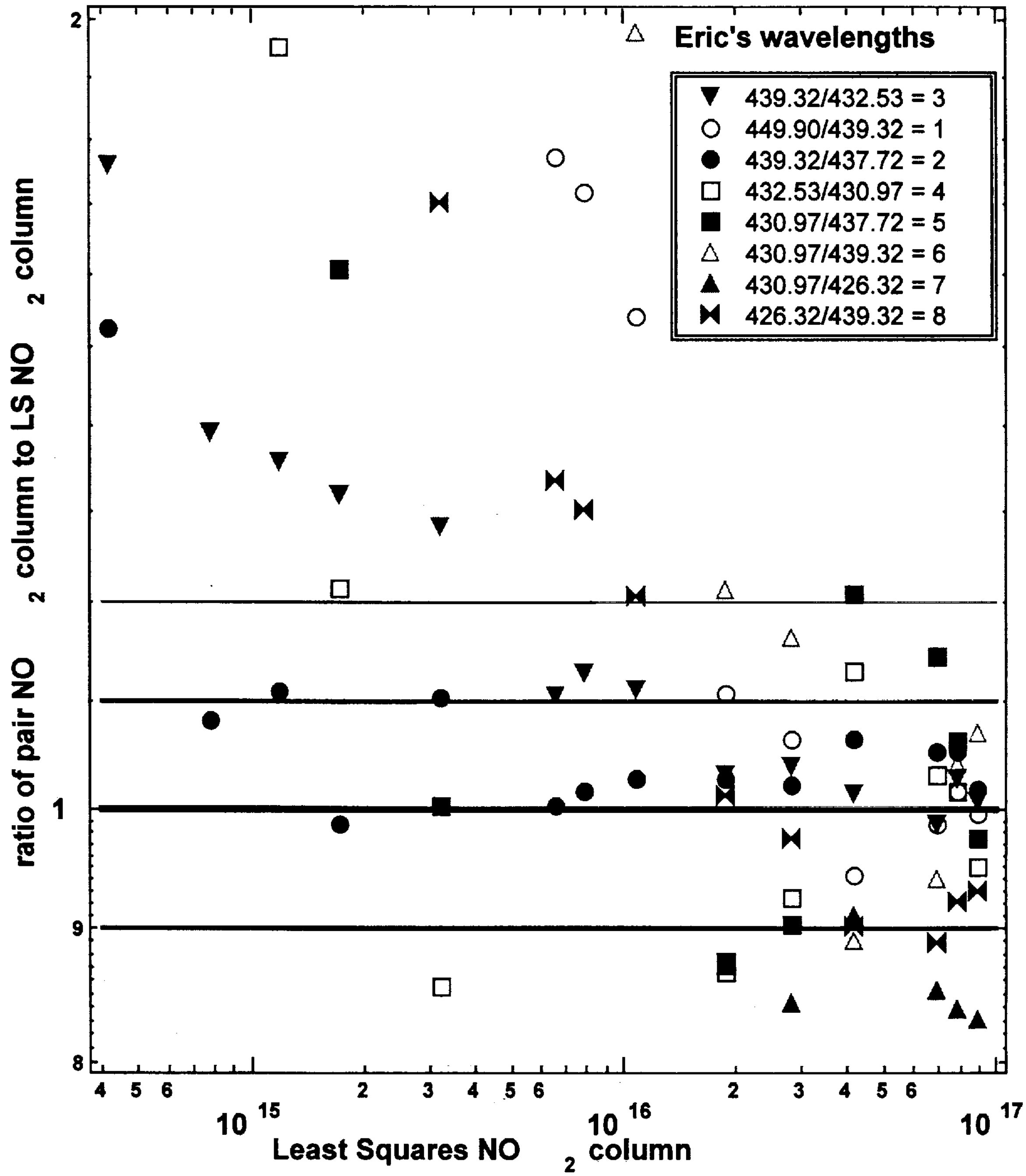
I then took Eric's wavelength pairs to derive independent NO_2 slant abundances at several solar zenith angles using data from which everything had been removed except NO_2. This left sky data with a very obvious NO_2 spectrum in it to work from for each solar zenith angle, and from which Ring and other things had been removed. These ratios produced the NO_2 slant columns (symbols) shown in the following figure, each one corresponding to a different pair ratio. The solid line is the data reduced using the full spectrum with the nonlinear least squares, and which should be very accurate. You have already seen this figure. I used a day with air



pollution on purpose, so the curve would not be smooth, but

Figure 2. Slant column NO_2 derived from the least squares analysis (solid line) and from Eric's wavelength pairs (symbols) as a function of solar zenith angle (time) for 4 April 1995 at Fritz Peak Observatory, Colorado. Observations are of the zenith sky. Ring and all effects except NO_2 and water have been taken into account in the data used to compute the pair ratios and deduce NO_2. The numbers to the right of the pairs are the array numbers in my program. Slant column is not smooth due to air pollution (purposely chosen).

would have jumps in it from dirty air containing NO_2 drifting over the instrument field of view. I thought this would provide a more stringent test. The next figure shows the ratio of the pair-derived NO_2 to the least squares-derived NO_2 plotted against the least squares-derived NO_2, once



again for Eric's wavelengths. This graph illustrates the quality of the fit.

Figure 3. Ratio of pair-derived NO_2 to least squares-derived NO_2 plotted against least squares-derived NO_2 for Eric's wavelength pairs. Marked are the 1.00 perfect fit, and $\pm10\%$ and +20% lines.

Figure 4 shows the same data, but with shifts randomly selected for ±0.1 nm in the filter central wavelength.

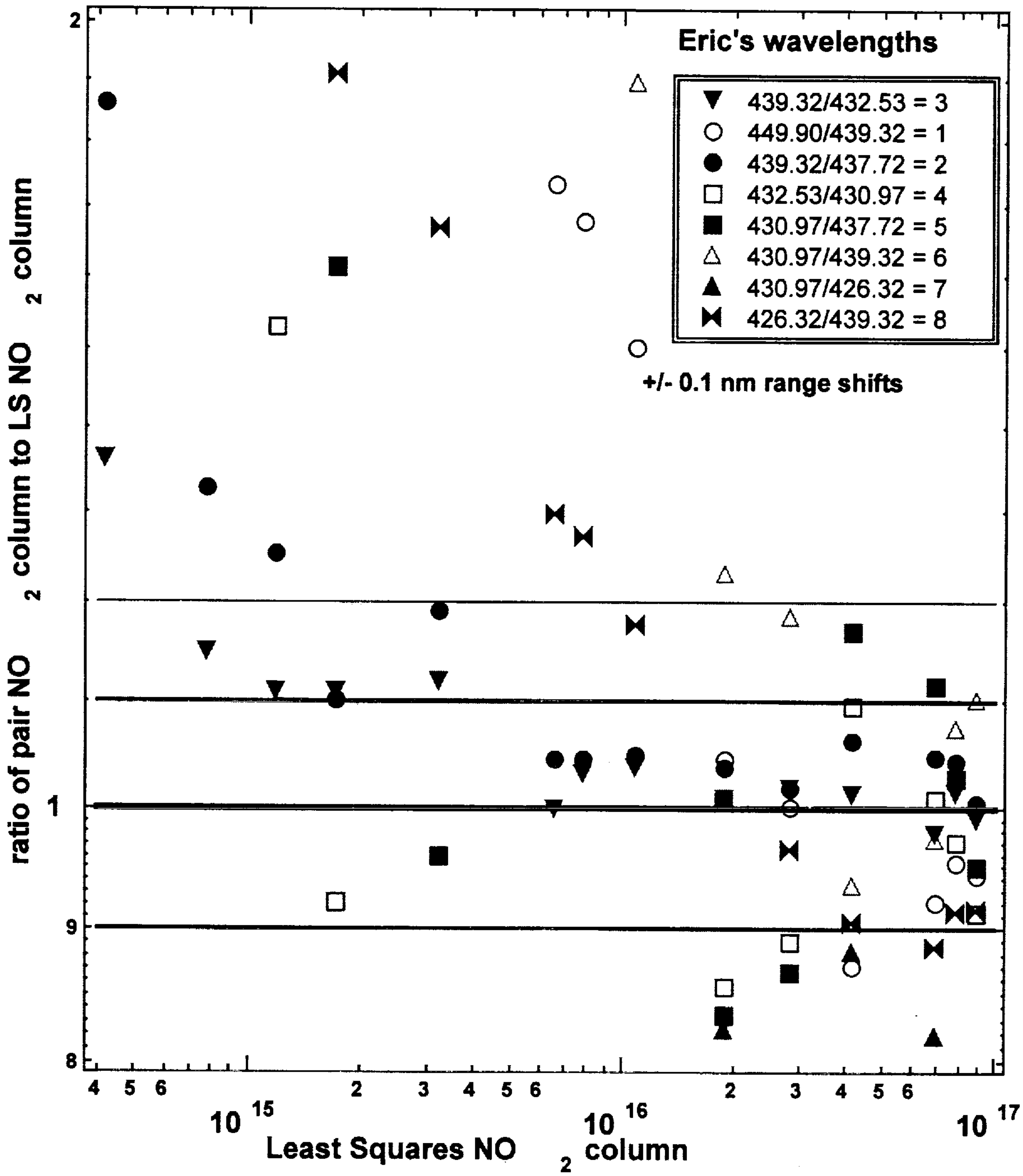


Figure 4. Eric's wavelengths with shifts ±0.1 nm.

The errors are larger, as expected, but the fits are not very good to start out with, so the next figures show the effect on the best wavelength pairs in the spectral region 425 - 455 nm for fits within ±10% above $5x10^{15}$ cm^{-2}.

Figure 5 shows the pair-derived NO_2 ratioed to the least squares-derived NO_2 plotted against the least squares-derived NO_2 column and sorted for 10% agreement for columns greater than $5x10^{15}$ cm^{-2}.

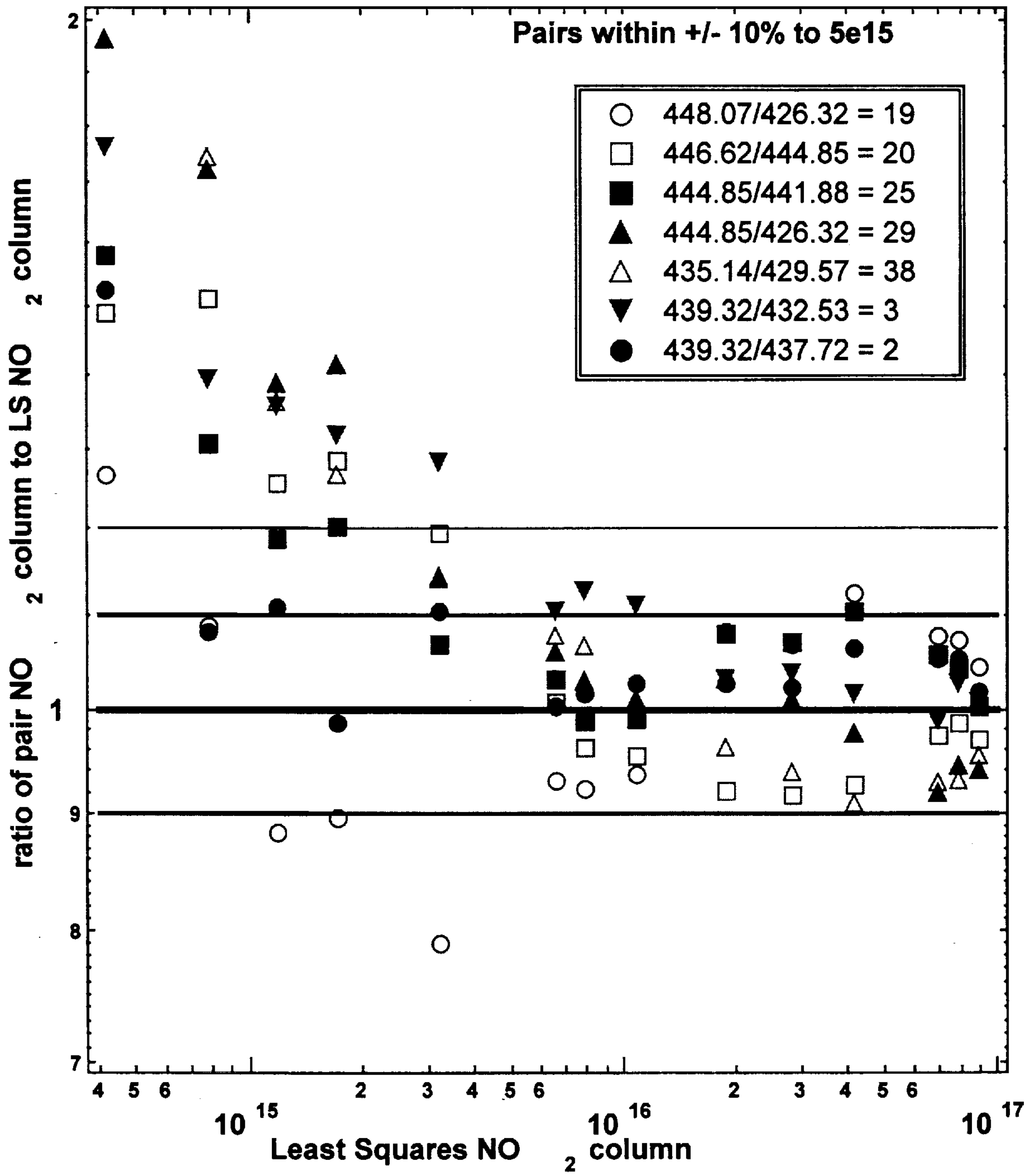


Figure 5. Pair-derived NO_2 ratioed to the least squares-derived NO_2 plotted against the least squares-derived NO_2 column and sorted for 10% agreement for columns greater than $5x10^{15}$ cm^{-2}.

The following graphs show the effect of an error range ± 0.1 and 0.2 nm shifts in the centers of the filter pairs chosen in Figure 5.

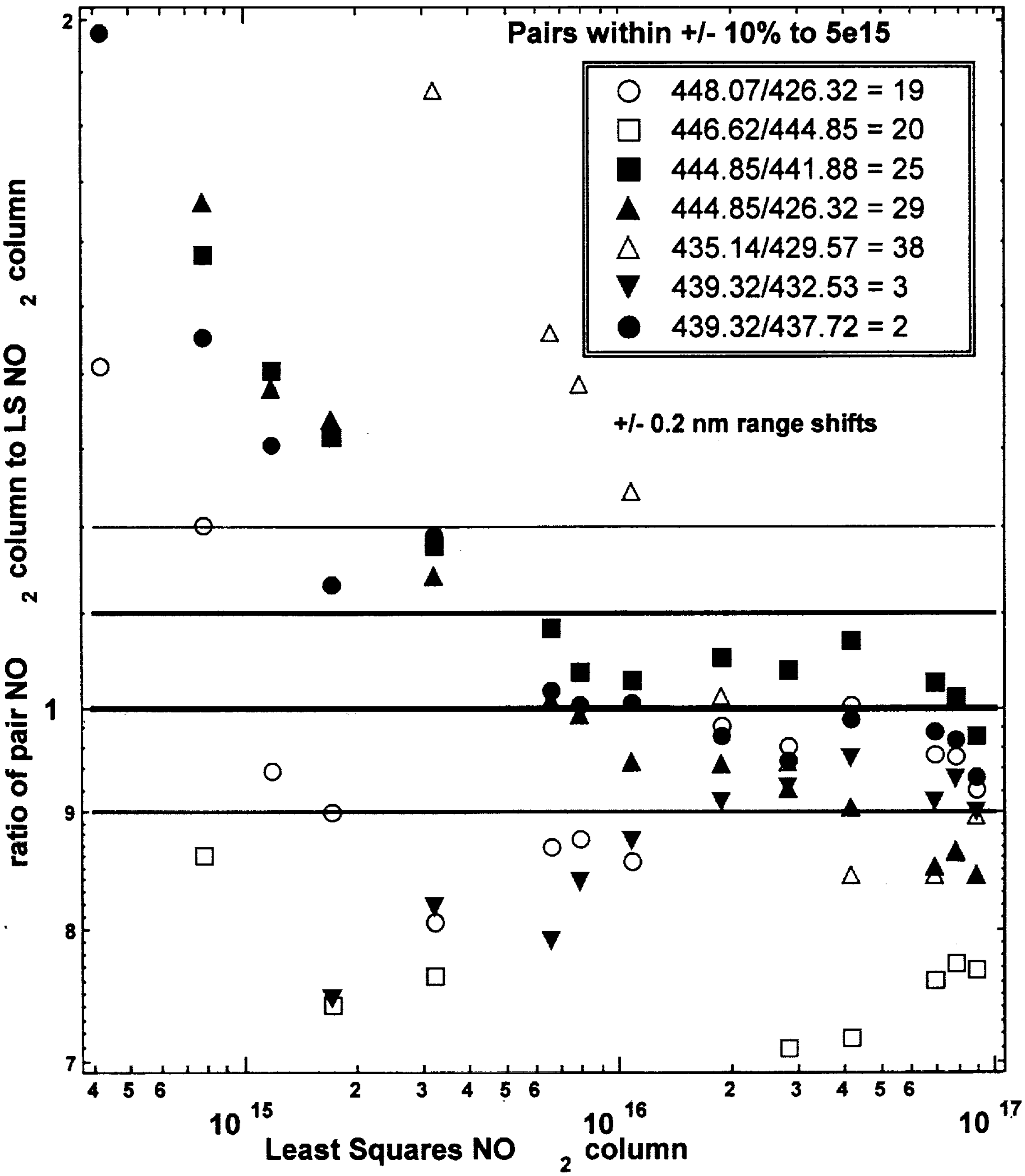


Figure 6. Same as Figure 5, but with filter centers shifted 0.2 nm randomly.

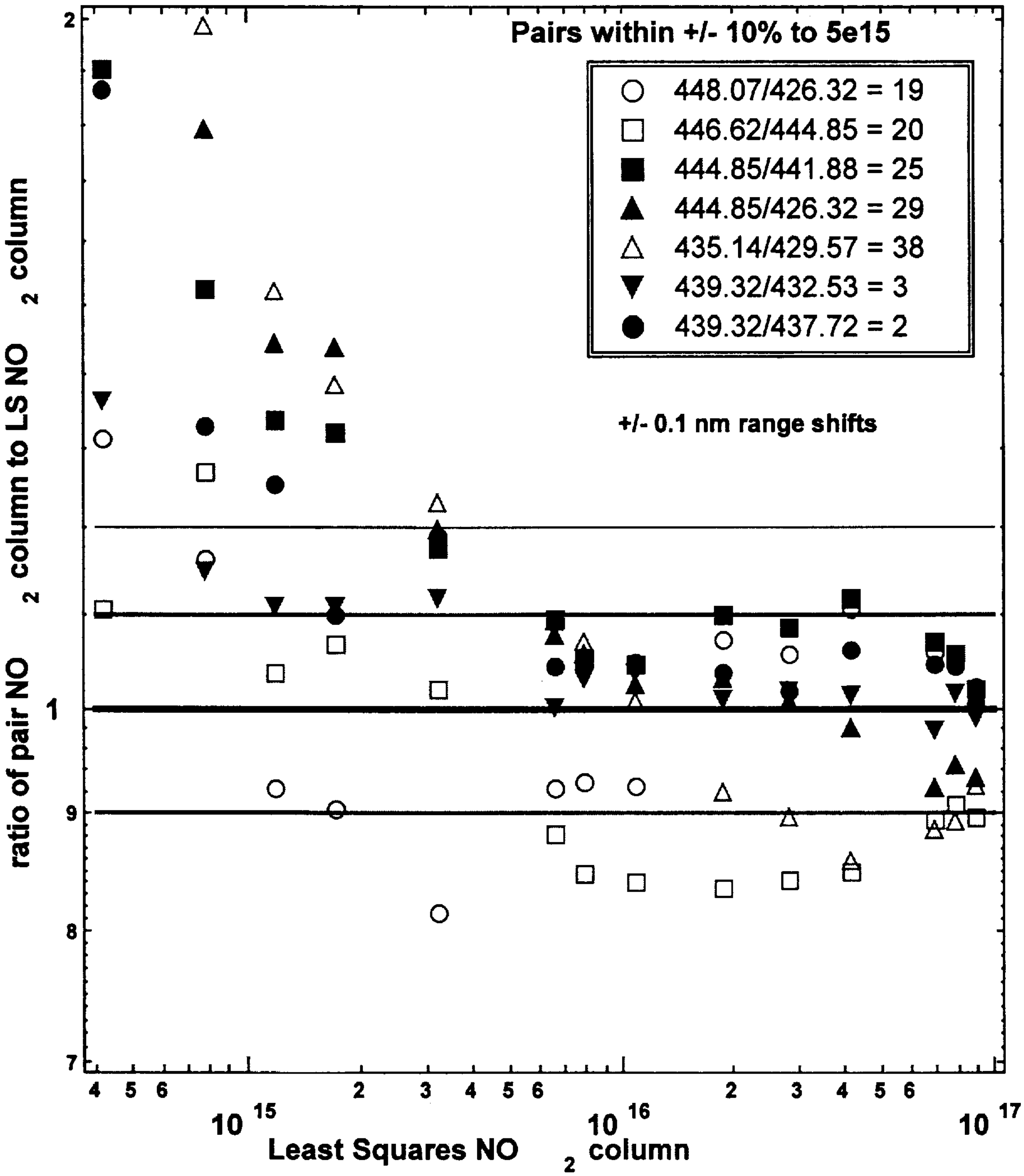


Figure 7. Same as Figure 5, but shifts 0.1 nm.

The next figures show the results for the best pairs, as identified in the report of 3.24.99.

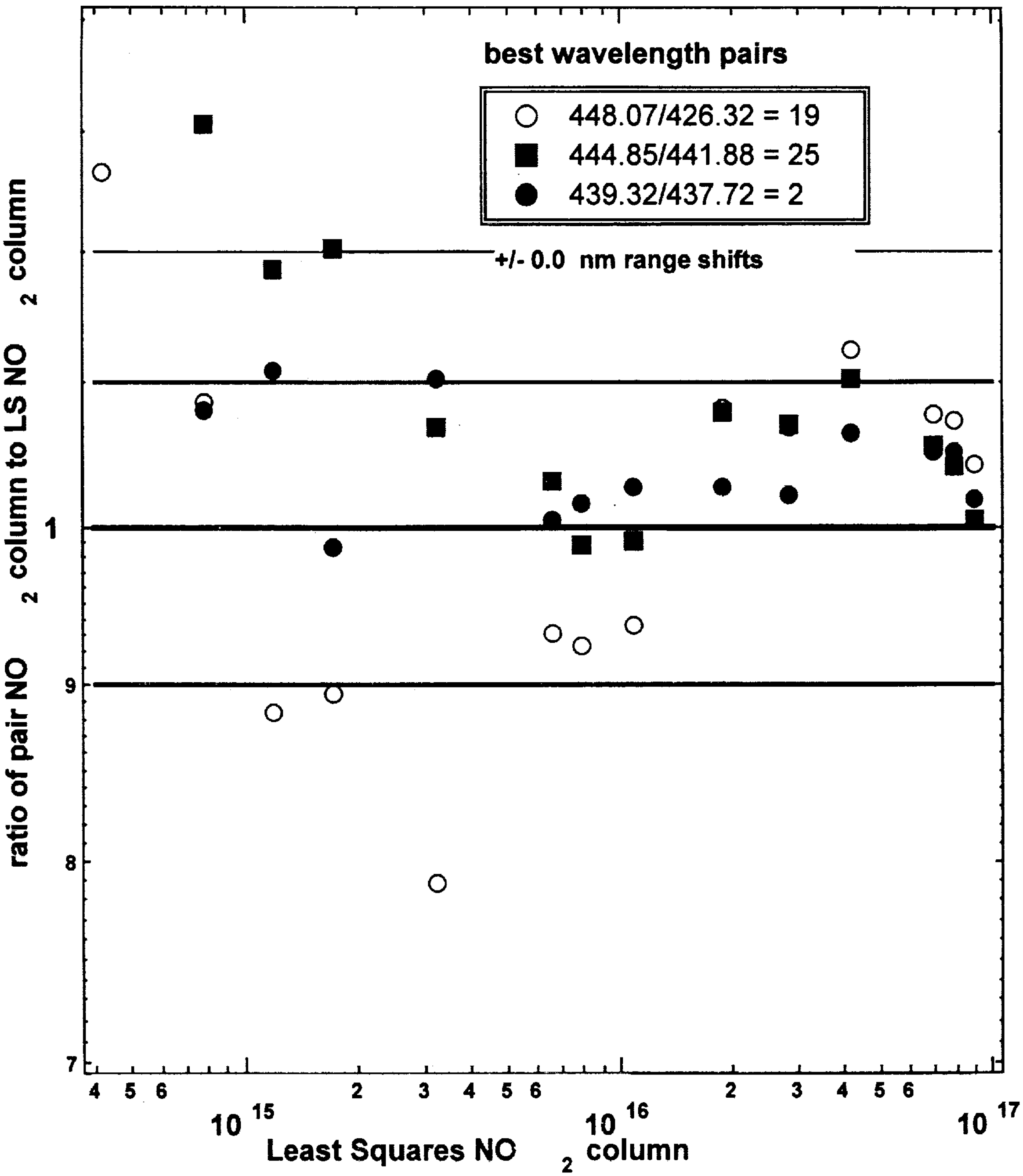


Figure 8. The best fitted pairs over the range of NO_2 column (report 3.24.99) with no shift.

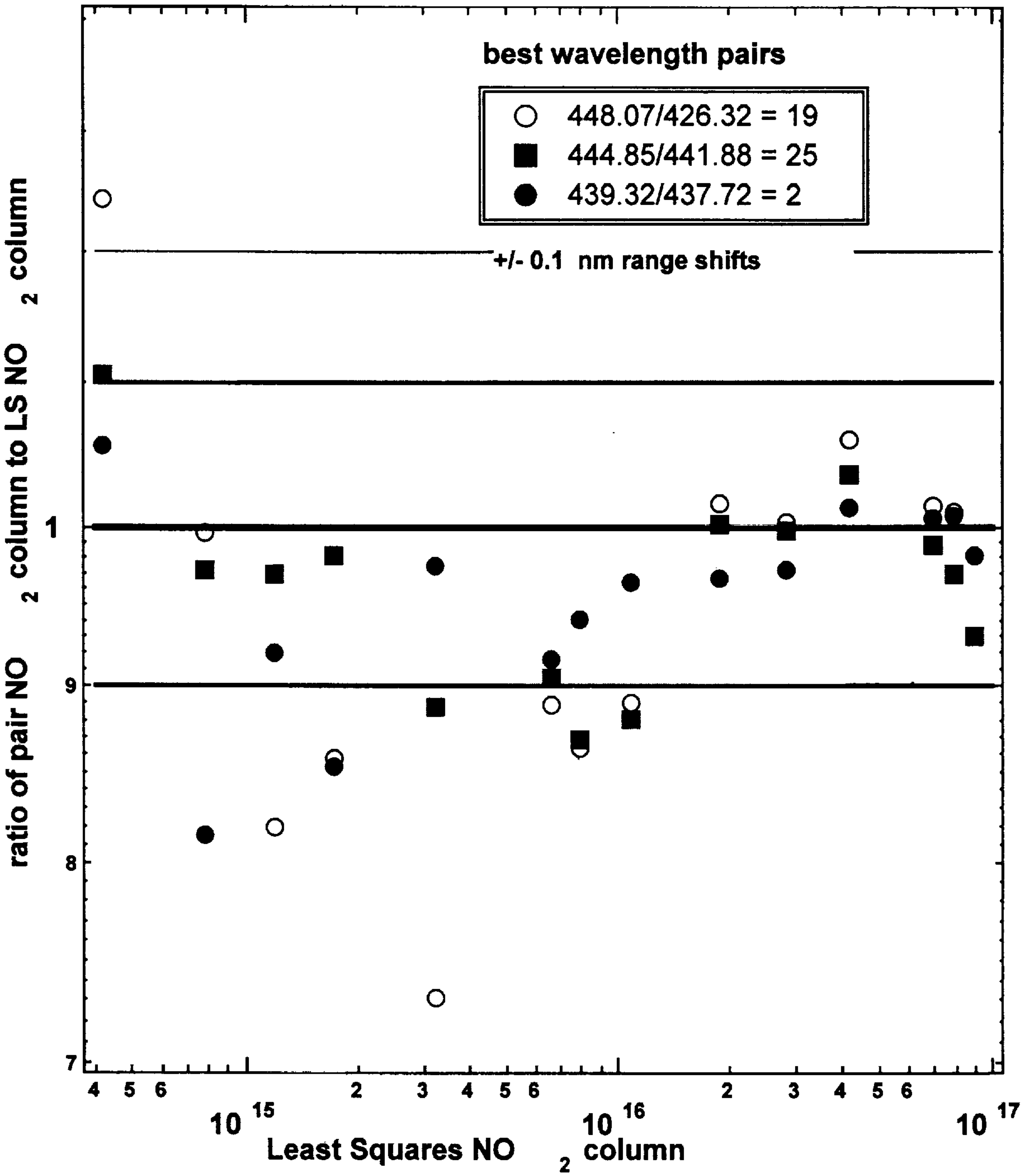


Figure 9. Same as Figure 8, but shifted +/-0.1 nm.

These results show that generally the results stay within the 10% error bars and, with one exception, within 20% of recovered NO_2 when shifted by the error we were planning on giving to Barr ($\pm$0.1 nm), and all as Eric has shown in the past.

Thus, it seems we have made a good choice of error for the filter centers at $\pm$0.1 nm..

CHyMERA NO_2 Null Pair Calculations
G.H. Mount
30 March 1999

Figure 1 below shows the NO_2 cross section peaks and valleys in spectral region 425 - 455 nm.

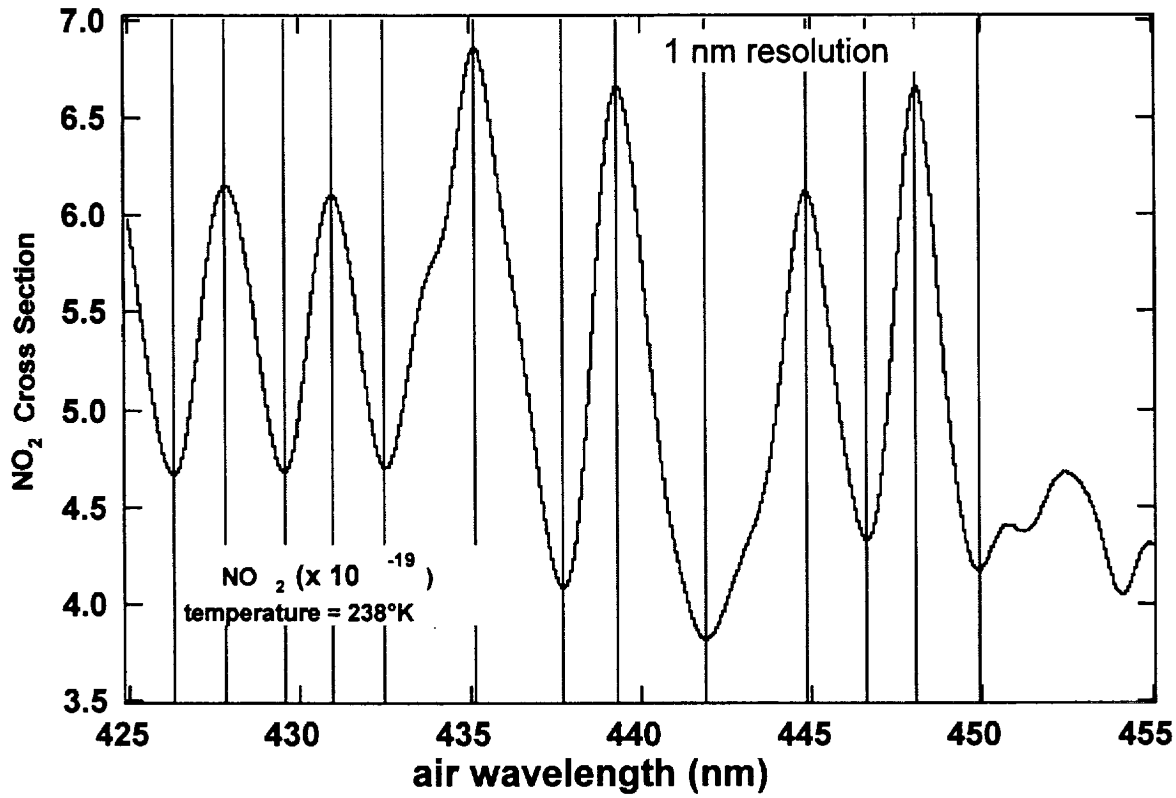


Figure 1. NO_2 cross section at 1 nm resolution in air 425 - 455 nm.

I have begun looking at wavelength pairs for a null NO_2 determination (one where the cross sections at two wavelengths are equal) in order to provide an estimate of noise, etc. since a null pair should return no derived NO_2 signal. This will be essential to proving the error budget out, and demonstrating that we don't see it when we should not. Obviously, there are nearly an infinite number of pairs that can be used just based on cross section equality. Therefore, I have concentrated on pairs where equal cross section to a peak or valley wavelength can be obtained at another wavelength; and for some pairs (on the red side of Figure 1) just taken points half way up/down the spectral features that correspond for several lines. The initial results for a large number of null pairs is shown in Figure 2. Plotted is the difference in normalized residual ratio against solar zenith angle. The NO_2 cross section does not come into play here since the difference between the wavelength pairs is zero. The numbers vary about $\pm$0.6%, a quite large number.

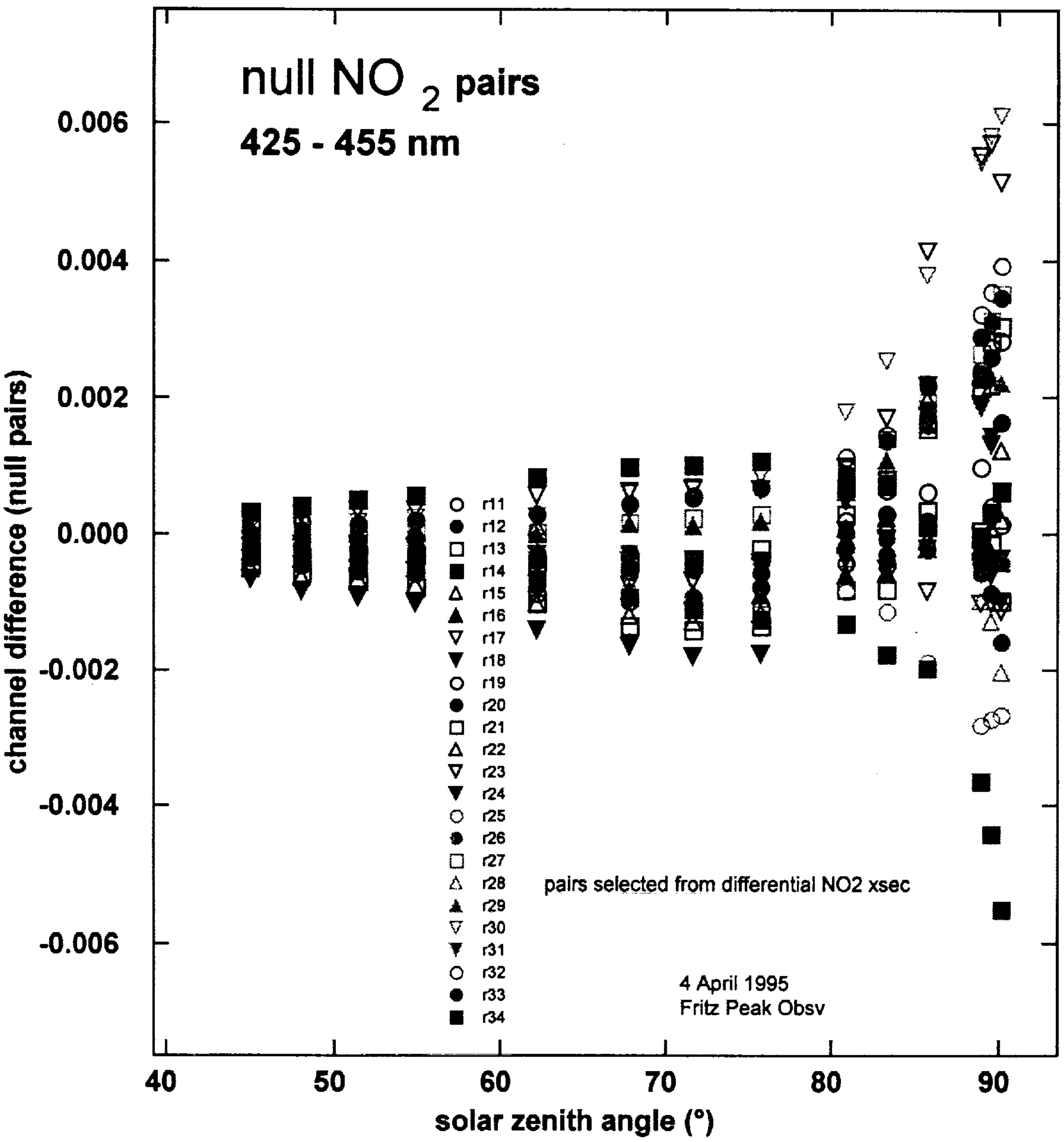


Figure 2. Plotted is the difference in normalized residual ratio against solar zenith angle for a number of null wavelength pairs. The NO_2 cross section does not come into play here since the difference between the wavelength pairs is zero.

Sorting for the best null pairs, Figure 3 below is produced. Here the scale is $\pm 0.1\%$. The best null pair is the one numbered r15. It is within about 0.02% of zero for all solar zenith angles. The wavelengths of this null pair are *approximately* 426.32 and 429.57 nm. One of these wavelengths is on both Eric's and George's recommended wavelength list (426.32 nm). However, the cross section at 426.32 nm is 4.66×10^{-19} cm^2 and the cross section at the other feature is 4.67×10^{-19}. Thus, technically we cannot choose the pair as 426.32/429.57 since the cross section difference is not zero and there is no way to get the second feature to 4.66 - it just does not dip that low. The wavelengths corresponding to 4.66×10^{-19} at the 426.32 dip are

426.22 and 426.41 nm, or about $\pm$0.1nm from the center of the spectral feature. Since this is within the tolerance for Barr Associates, it seems that use of the 426.32 nm wavelength filter as one part of the NO_2 null pair will work just fine.

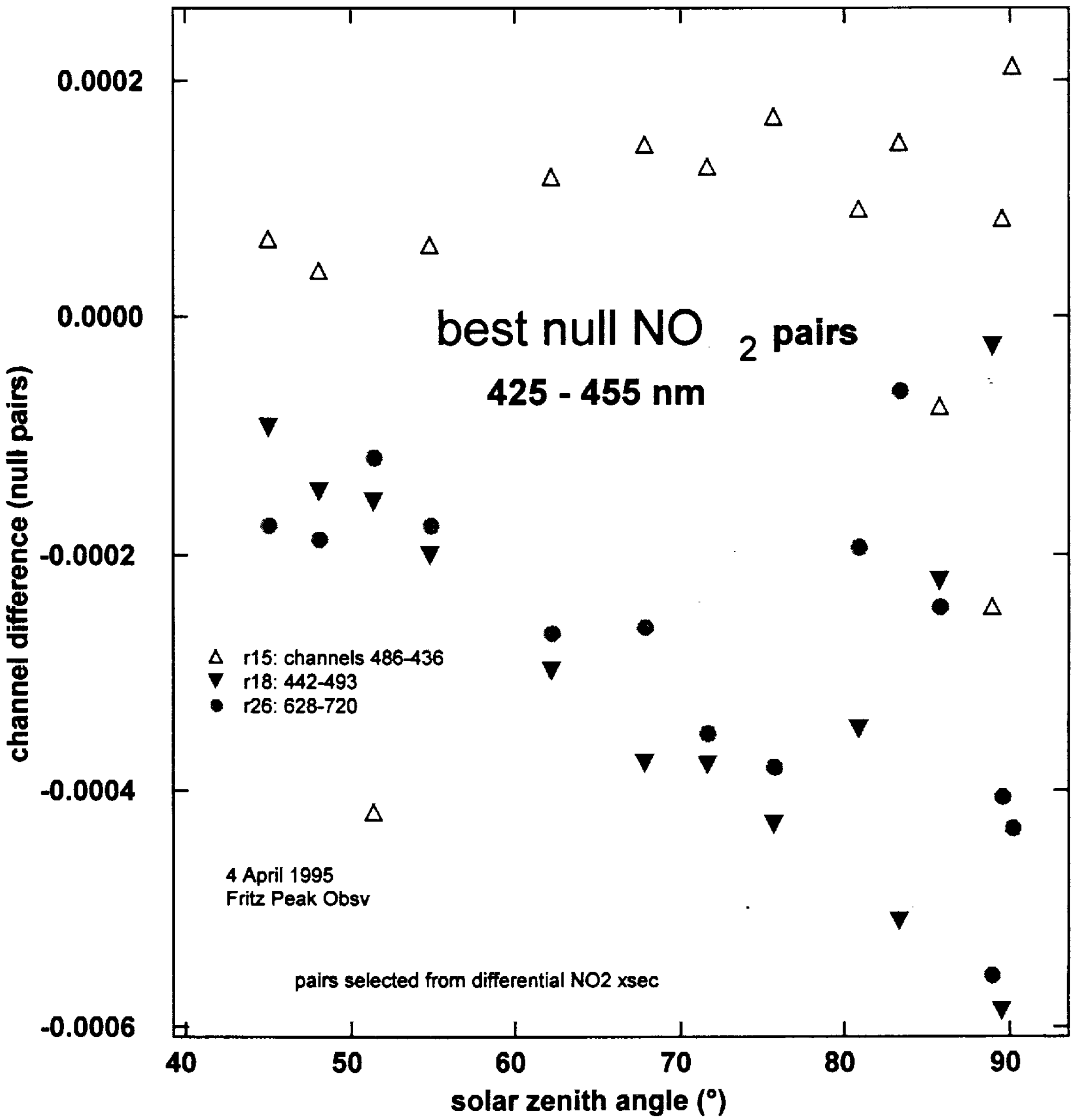


Figure 3. The best null pairs chosen from Figure 2. The best pair is the [426.41, 426.22] / 429.57 nm pair, r15.

Thus, the recommended filter wavelengths for the null pair are: 426.32 and 429.57 nm. This conveniently adds another cross section valley to the list, although the quality of NO_2 pair retrieval using 429.57 nm according to both George and Eric, is poor.

Eric - do you have some thoughts on null pairs????

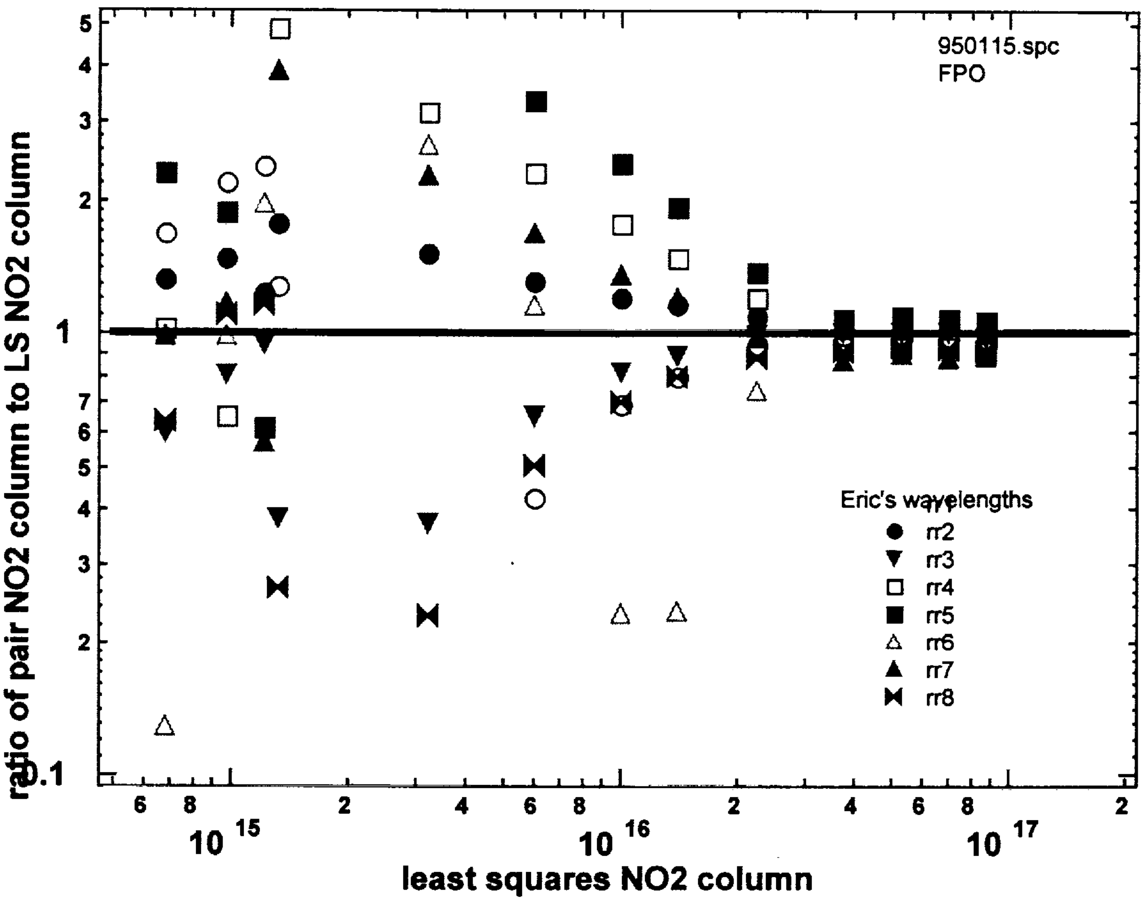


Figure 2. Data for 15 January plotted against the least squares abundances.

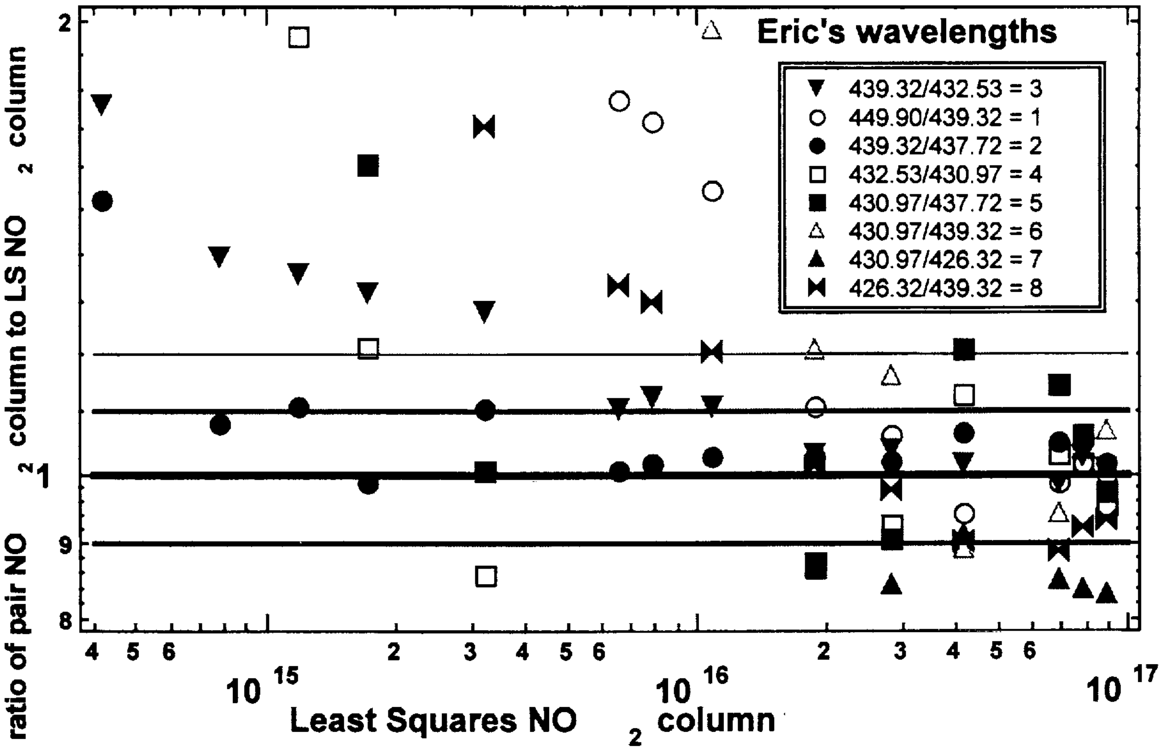


Figure 3. Same as in the 24 March report for 4 April and Eric's pairs.

The coding for the colors and symbols is the same in the three figures with the actual wavelength code in Figure 3. The interesting thing is that ratios which fit best in the 4 April data (ratios 2 and 3) are still the best fits, but in the winter data the fits between 1 x 10^{15} and 6 x 10^{15} are quite poor (for all the Eric pairs). I do not understand this. I continued repeating the analysis of 24 March with 43 pairs of wavelengths including Eric's.

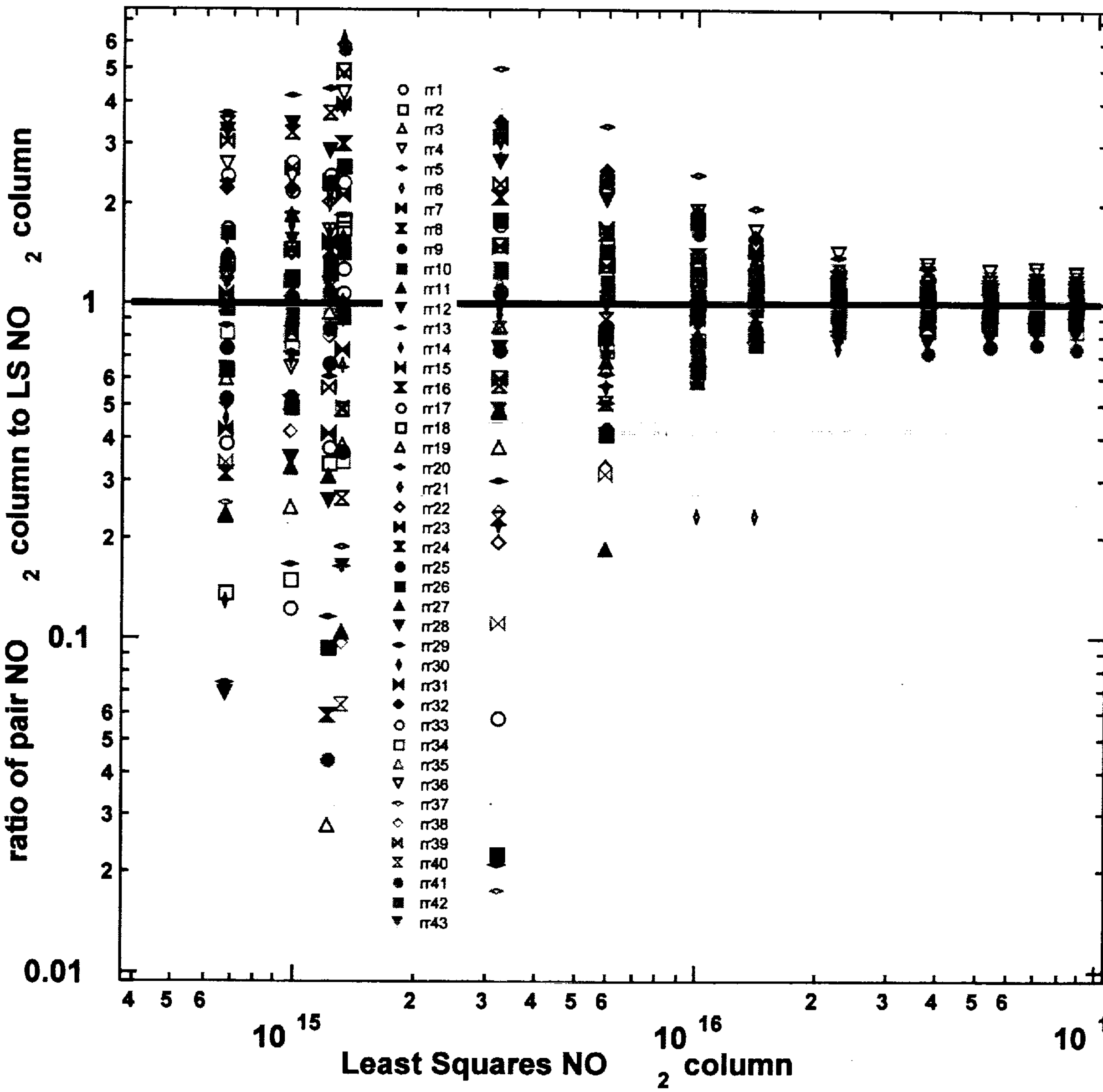


Figure 4. The same 43 pairs of wavelengths selected for the 4 April analysis (Fig 5, 24 March report)

There is a wide range of returned NO_2 columns from the various pairs, just as there was before. Figure 5 shows the same data, but with most of the outlyers removed, but pairs 2 and 3 left in since these overlap Eric's wavelengths and they both fit within $\pm 10\%$ to 5×10^{15} in the 4 April data set [note I screwed up the color and symbols here - they are not the same as above]. Both of these pairs fit poorly now. The best fit pairs are now: 17, 9, 19, and 30 which use wavelengths 426.32, 439.22, 441.88, 446.62, 448.07, and 449.90. Of these three are on Eric's original list, and four are on the best wavelength pair list from the 24 March analysis.

CHyMERA NO_2 Pair Calculations
G.H. Mount
7 April 1999

I have taken another set of Fritz Peak data, and repeated my analysis reported on 24 March. This time I chose a day in winter with small values of slant column NO_2 and a long slow move through twilight figuring that might give us a better handle on what is happening at low values so we could see what the noise might be better. The date chosen was 15 January 1995 (the date for the 24 March report was 4 April, which was chosen as as polluted day to see if the pairs repeated the jumps in column) which was a clean, clear day with a very smooth zenith angle dependence. I started with Eric's wavelength pairs. Remember that his air wavelengths are: 426.32, 430.97, 432.53, 437.72, 439.32, and 449.90 nm [air]. The wavelengths that fit best from the FPO data that overlapped Eric's were 426.32, 437.72, 439.32.

The data was reduced in the same manner as for the 24 March report. Figure 1 below shows the zenith angle dependence of the pair-derived NO_2 as well as the least squares NO_2 fit to the entire spectrum. Codes are the same as in the March report, and are shown here in Figure 3.

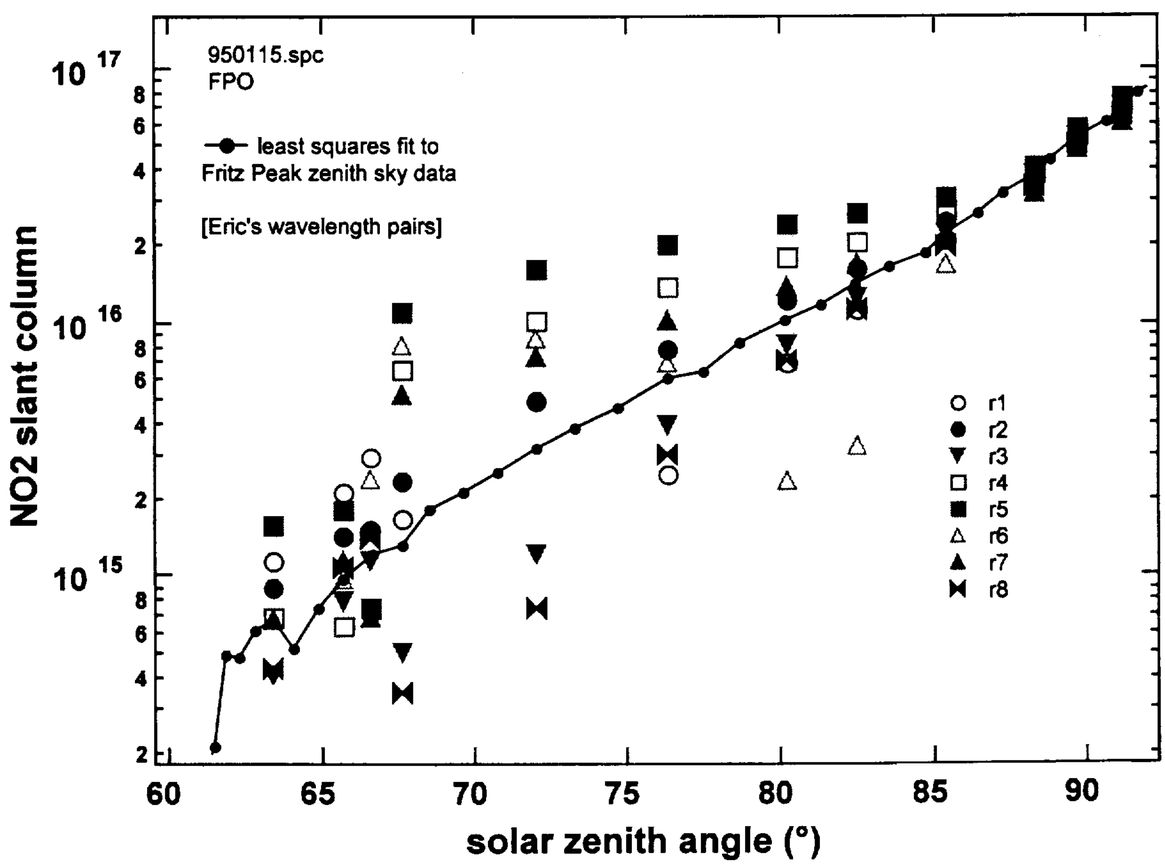


Figure 1. Zenith angle dependence of the 15 January data for Eric's wavelengths.

Figure 2 below shows the same 15 January data plotted against least squares abundances derived from the entire spectrum for Eric's wavelength list. Figure 3 shows the data for 4 April directly out of the 24 March report.

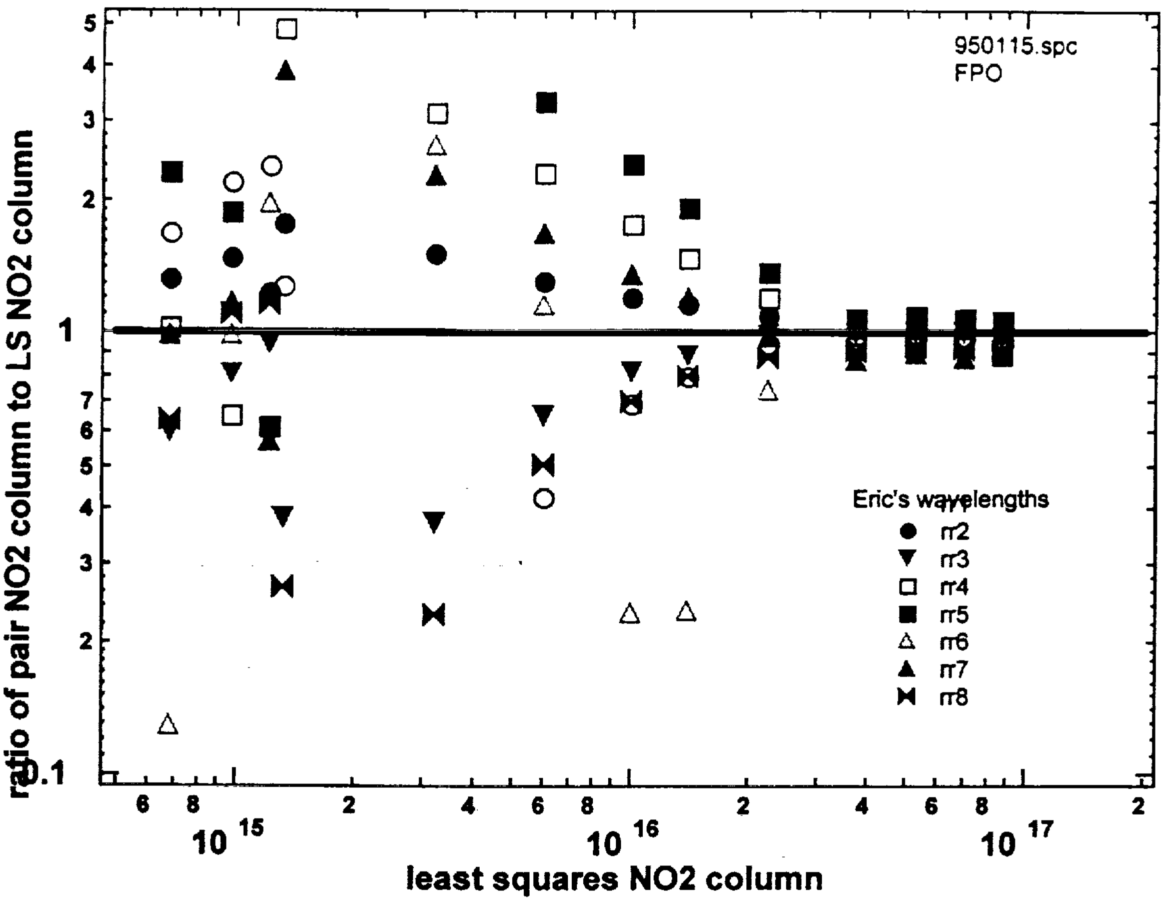
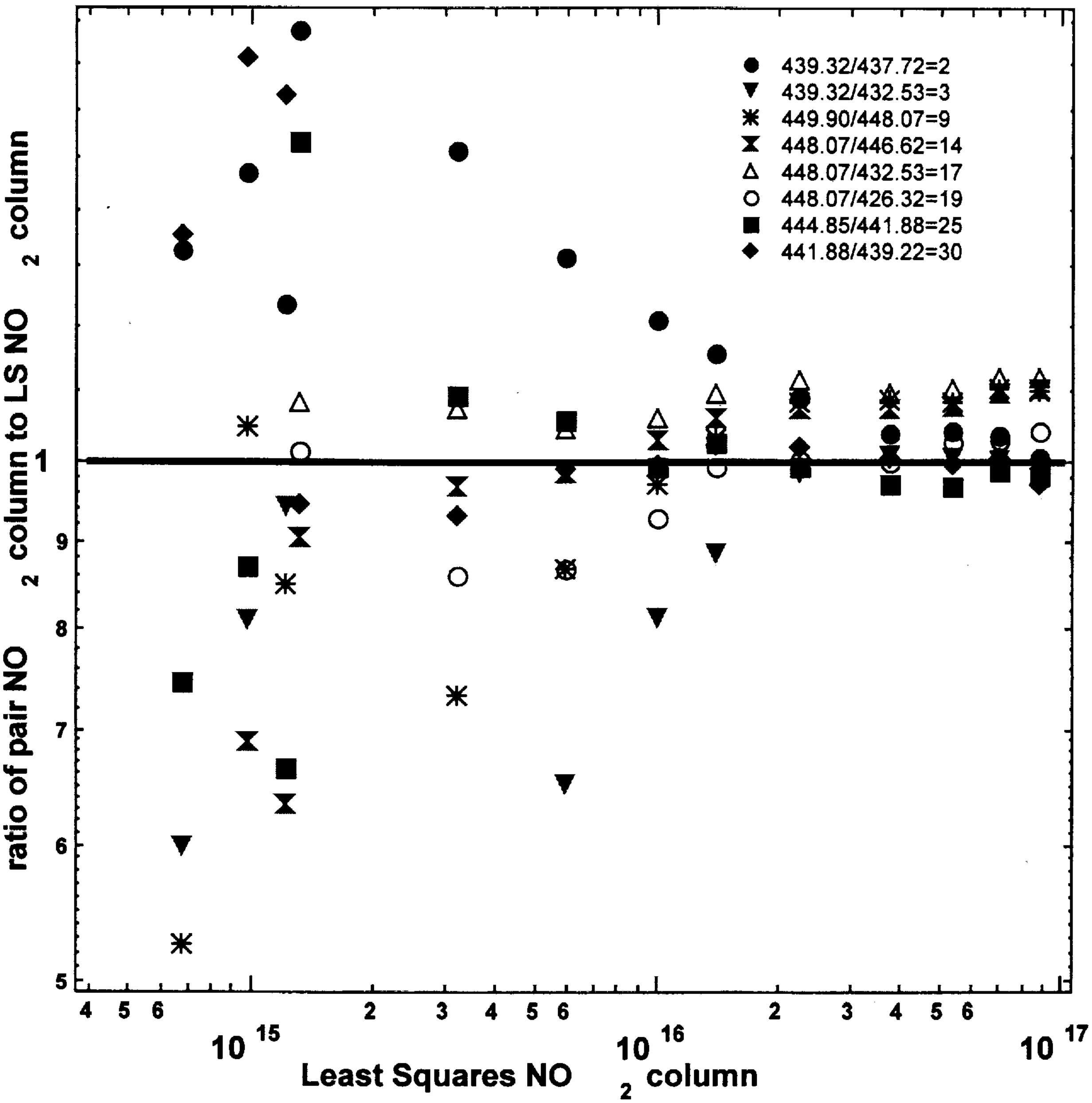


Figure 2. Data for 15 January plotted against the least squares abundances.



I cannot say that I understand why things are so different in the 15 January data set. It is a real data set taken at a different time of the year, so certainly changes are expected. But the lack of any good fit in the high x 10^{15} abundances is quite perturbing. The fits where expected to be good (above 1 x 10^{16}) vary about 10%, a surprisingly large number. The fits in this region for the 4 April data set were also high like this (~ 10%). Why it is not symmetric, I do not know.

I plan to do some more analysis and try to see how much this all varies. I think that with 4 of Eric's 6 wavelengths confirmed, that the list is likely okay. The problem I see is "why it does not fit better to the least squares data". The 4 April data set fit pretty well across the full range of NO_2 slant column.

NO_2 Temperature Dependence Problems
30 May 1999
G H Mount

In our meeting earlier this week, we discussed the potential effects of NO_2 cross section temperature dependence on retrievals and whether or not there is any way that we can minimize the effect through a judicious choice of wavelengths. As the temperature is lowered, the NO_2 spectrum narrows and the peaks separate more from the valleys, all as expected. Thus, the observed satellite column observations of the stratosphere (cold) and tropospheric boundary layer (warm) are always a mixture of the different temperature regimes which require different cross section blends for proper analysis. There is not enough information in a column to uniquely choose a blend, so usually a single temperature is chosen. Figure 1 shows our final selection of NO_2 wavelengths for CHyMERA at 1 nm resolution and 238°K, a temperature characteristic of the stratosopheric NO_2 layer at about 27 km.

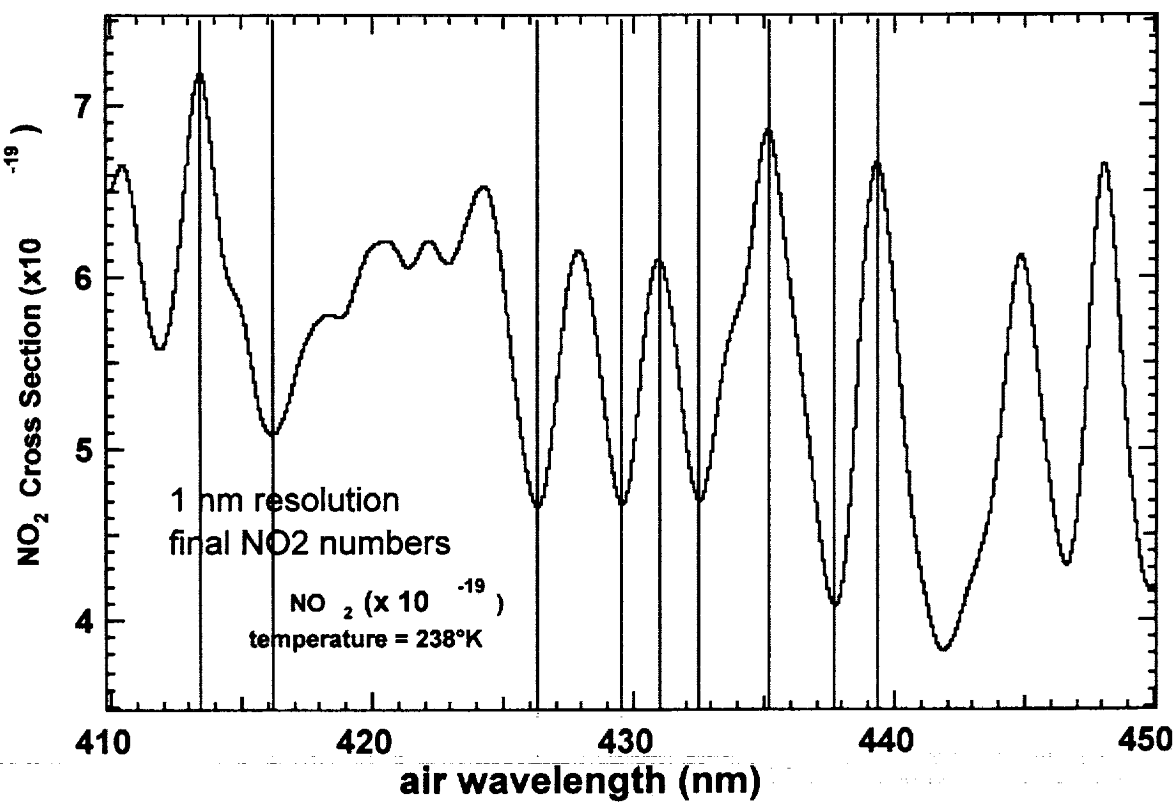


Figure 1. NO_2 wavelengths selected for CHyMERA at 1nm resolution. Null pair is 426.3, 429.6 nm.

Figure 2 shows the NO_2 cross sections at 238°K and 293°K. The warmer cross section has a smaller peak to peak variation, as expected.

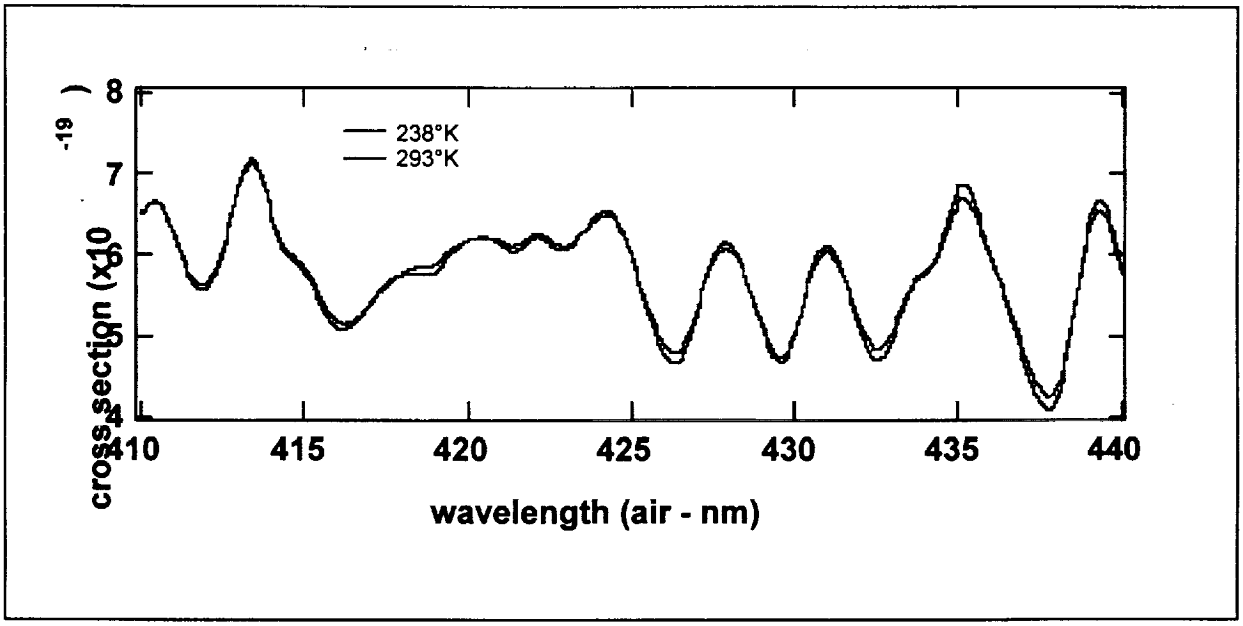


Figure 2. NO_2 cross sections at 238°K and 293°K at 1 nm spectral resolution

Figure 3 shows the final wavelength selection for NO_2 and the associated cross sections

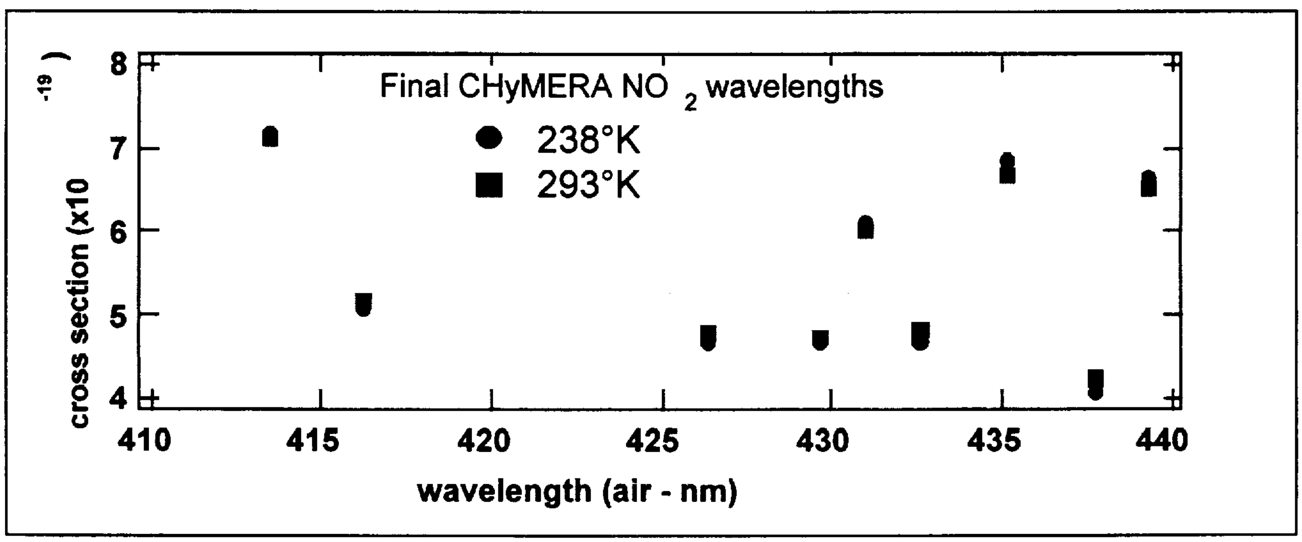


Figure 3. Cross sections chosen for CHyMERA.

Figure 4 shows *all* the possible pair ratios at the two temperatures, even ones we would not consider using, plotted against a "pair index number" which is listed in probably unreadable form on the graph. Here is a readable form with the cross section differences [x 10^{-19}] shown so the useful pairs can be identified

0	413.42/416.17	1.99
1	413.42/426.32	2.35
2	413.42/429.57	2.40
3	413.42/430.96	1.12
4	413.42/432.54	2.31
5	413.42/435.15	0.46
6	413.42/437.73	2.89
7	413.42/439.32	0.61
8	416.17/426.32	0.36
9	416.17/429.57	0.41
10	416.17/430.96	0.87
11	416.17/432.54	0.33
12	416.17/435.15	1.53
13	416.17/437.73	0.90
14	416.17/439.32	1.38
15	426.32/429.57---null	0.04
16	426.32/430.96	1.22
17	426.32/432.54	0.04
18	426.32/435.15	1.89
19	426.32/437.73	0.54
20	426.32/439.32	1.74
21	429.57/430.96	1.27
22	429.57/432.54	0.08
23	429.57/435.15	1.94
24	429.57/437.73	0.49
25	429.57/439.32	1.79
26	430.96/432.54	1.19
27	430.96/435.15	0.68
28	430.96/437.73	1.76
29	430.96/439.32	0.51
30	432.54/435.15	1.86
31	432.54/437.73	0.57
32	432.54/439.32	1.70
33	435.15/437.73	2.43
34	435.15/439.32	0.16
35	437.73/439.32	2.28

The most useful pairs are the ones *not* near 1.00, except for the selected null pair, which is index number 15. As expected, the null pair index 17 has an equally small cross section difference, but an even small temperature dependence. Thus, we have two null pairs which could work equally well, although pair 15 worked better in the real analysis. In any case, Figure 5 shows the final result, which is the ratio of the pair ratios at the two temperatures. Thus, Figure 5 indicates the change in cross section ratio between the two temperatures. This figure shows that index 17 may be somewhat better as a null pair than the originally selected index 15.

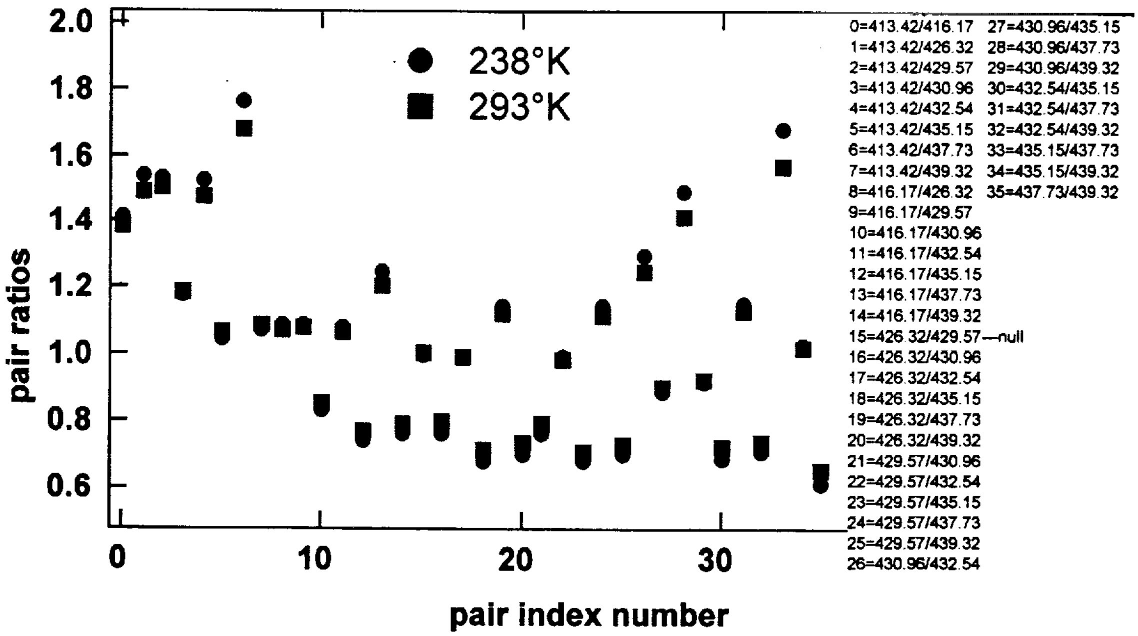


Figure 4. Pair ratios for all possible NO_2 pairs plotted against the index number for the pair.

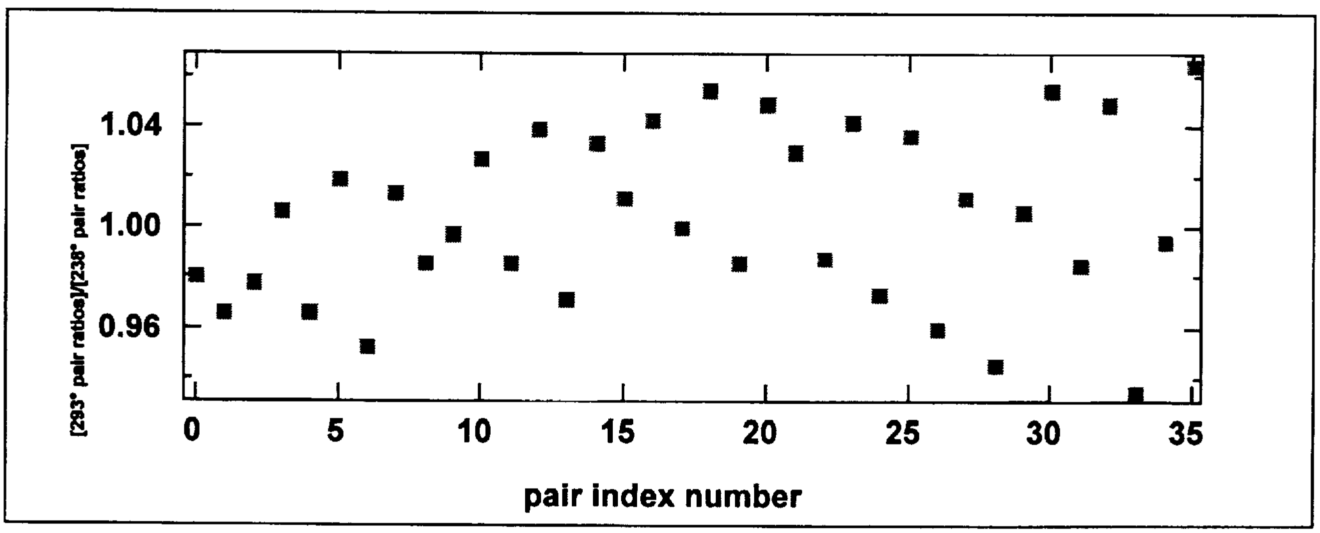


Figure 5. Ratio of pair ratios at the two temperatures vs. index number of pair.

This final graph shows the temperature sensitivity of the various pairs. In all cases, the maximum change in using an incorrect temperature for the reduction is about ±5%. This is certainlly an acceptable error.

In conclusion, there appears to be no significant reason to select wavelength pairs based on temperature.

Appendix B – Barr Associates Filter Measurements

- Strip Filter composition and arrangement
- Strip Filter size and placement measurements
- Transmission measurements

CHyMERA Filter Strips: 16 Filters with dimensions 33 mm X 1.34 mm
2 Edge filters with dimensions 33 mm X 5.34 mm
Overall Dimensions: 33 mm X 33 mm X 6.2 mm thick All Wavelengths in air

Filter (nm)	Glass1	Glass2	Glass3	Thickness	F/#
310.7	Schott UBK7	Schott UG11	Schott UBK7	(mm)	
thickness (mm)	1.1	4	1.1	6.2	4.63
312	Schott UBK7	Schott UG11	Schott UBK7		
	1.1	4	1.1	6.2	4.63
313.1	Schott UBK7	Schott UG11	Schott UBK7		
	1.1	4	1.1	6.2	4.63
317.4	Schott UBK7	Schott UG11	Schott UBK7		
	1.1	4	1.1	6.2	4.63
322.2	Schott UBK7	Schott UG11	Schott UBK7		
	1.1	4	1.1	6.2	4.63
329.2	Schott UBK7	Schott UG11	Schott UBK7		
	1.1	4	1.1	6.2	4.63
339.9	Schott UBK7	Schott UG11	Schott UBK7		
	1.1	4	1.1	6.2	4.63
387.9	Schott BG3	Phila Optics BGG28	Schott B270		
	2	2.7	1.5	6.2	4.63
393.3	Schott BG3	Phila Optics BGG28	Schott B270		
	2	2.7	1.5	6.2	4.63
413.4	Schott B270	Phila Optics BGG22	Schott B270		
	1.6	3	1.6	6.2	4.63
416.2	Schott B270	Phila Optics BGG22	Schott B270		
	1.6	3	1.6	6.2	4.63
426.3	Schott B270	Phila Optics BGG22	Schott B270		
	1.6	3	1.6	6.2	4.63
429.6	Schott B270	Phila Optics BGG22	Schott B270		
	1.6	3	1.6	6.2	4.63
431	Schott B270	Phila Optics BGG22	Schott B270		
	1.6	3	1.6	6.2	4.63
432.5	Schott B270	Phila Optics BGG22	Schott B270		
	1.6	3	1.6	6.2	4.63
435.1	Schott B270	Phila Optics BGG22	Schott B270		
	1.6	3	1.6	6.2	4.63
437.7	Schott B270	Phila Optics BGG22	Schott B270		
	1.6	3	1.6	6.2	4.63
439.3	Schott B270	Phila Optics BGG22	Schott B270		
	1.6	3	1.6	6.2	4.63

Refractive index of glasses

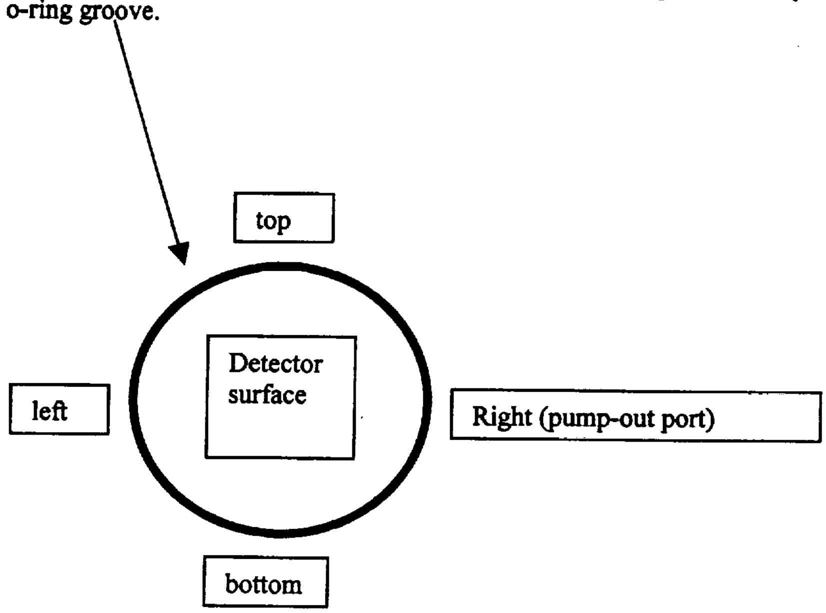
UG11 (wavelength - nm)	280.3	365	587.6	
	1.6	1.57	1.55	
UBK7	296.7	312.6	334.1	365
	1.5538	1.54852	1.54266	1.53622
BG3	302.1	435.8	587.6	1014
	1.55	1.52	1.51	1.5
BGG28 and BGG22	435.83	483.13	546.07	
	1.572	1.566	1.562	
B270	546	588		
	1.5251	1.523		

CHyMERA Detector Location and Depth Measurements:
1/10/2000 (V. Bly and S. Janz)

A travelling microscope with a precision (xyz)-translation station in Code 553 was used to measure the flatness of the detector, depth, and centeredness with respect to the dectector housing. All measurements are +/- 0.005 mm.

Depth: The surface of the detector was measured with respect to the detector housing on the flat portion of the housing rim near the o-ring groove.

Top: na
Left: 5.400 mm
Right: 5.458 mm
Bottom: 5.408 mm



Detector Flatness:

Left to right: 0.010 mm
Top to bottom: 0.014 mm

Centeredness: This was measured from the detector substrate edge to the inside wall of the o-ring groove.

Left: 46.070 mm
Right: 46.421 mm
Top: 46.416 mm
Bottom: 45.916 mm

CHYMERA Filter Measurements 12/29/99 V.T. Bly Code 553 GSFC

```
 -------------------
|    Silver Bar     |
|                   |
|                   |
|                   |
|                   |
| shades of blue    |
| shades of blue    |
|                   |
|    Purple Bar     |
 -------------------
```

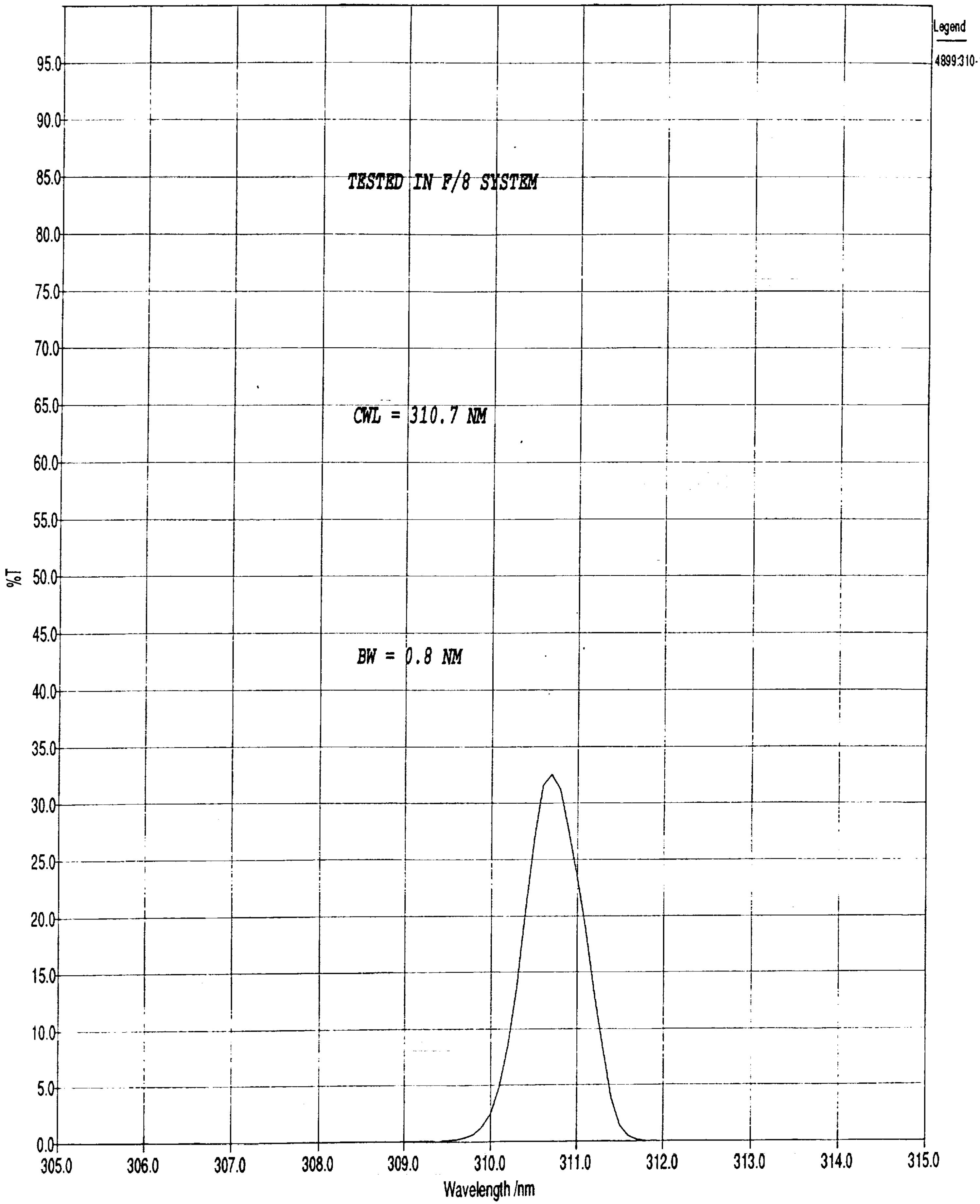
VARIATION IN HEIGHT (THICKNESS):

<table>
<tr><th></th><th>lf. side</th><th>rt. side</th><th>rt. side</th><th>delta</th></tr>
<tr><td>Silver Bar:</td><td>-0.00215</td><td>+0.00000</td><td>+0.00010</td><td>0.00010</td></tr>
<tr><td>1</td><td>-0.00195</td><td>-0.00010</td><td>+0.00050</td><td>0.00040</td></tr>
<tr><td>2</td><td>-0.00085</td><td>+0.00105</td><td>+0.00100</td><td>0.00005</td></tr>
<tr><td>3</td><td>-0.00070</td><td>+0.00105</td><td>+0.00110</td><td>0.00005</td></tr>
<tr><td>4</td><td>+0.00035</td><td>+0.00155</td><td>+0.00165</td><td>0.00010</td></tr>
<tr><td>5</td><td>+0.00055</td><td>+0.00170</td><td>+0.00165</td><td>0.00005</td></tr>
<tr><td>6</td><td>+0.00055</td><td>+0.00180</td><td>+0.00195</td><td>0.00015</td></tr>
<tr><td>7</td><td>+0.00055</td><td>+0.00215</td><td>+0.00195</td><td>0.00020</td></tr>
<tr><td>8</td><td>+0.00155</td><td>+0.00215</td><td>+0.00215</td><td>0.00000</td></tr>
<tr><td>9</td><td>+0.00155</td><td>+0.00310</td><td>+0.00330</td><td>0.00020</td></tr>
<tr><td>10</td><td>+0.00145</td><td>+0.00335</td><td>+0.00325</td><td>0.00010</td></tr>
<tr><td>11</td><td>+0.00140</td><td>+0.00410</td><td>+0.00405</td><td>0.00005</td></tr>
<tr><td>12</td><td>+0.00145</td><td>+0.00400</td><td>+0.00405</td><td>0.00005</td></tr>
<tr><td>13</td><td>+0.00195</td><td>+0.00400</td><td>+0.00405</td><td>0.00005</td></tr>
<tr><td>14</td><td>+0.00205</td><td>+0.00450</td><td>+0.00440</td><td>0.00010</td></tr>
<tr><td>15</td><td>+0.00240</td><td>+0.00450</td><td>+0.00440</td><td>0.00010</td></tr>
<tr><td>16</td><td>+0.00260</td><td>+0.00465</td><td>+0.00440</td><td>0.00015</td></tr>
<tr><td>Purple Bar:</td><td>+0.00020</td><td>+0.00250</td><td>+0.00265</td><td>0.00015</td></tr>
<tr><td>Purple Bar:</td><td>+0.00370</td><td>+0.00585</td><td>+0.00610</td><td>0.00025</td></tr>
<tr><td></td><td>lf side</td><td>rt side
meas 1</td><td>rt side
meas 2</td><td>delta
|m1-m2|</td></tr>
</table>

Overall thickness at right side of silver bar = 0.236" +/-0.0005", thickness at other locations varies as tabulated above.

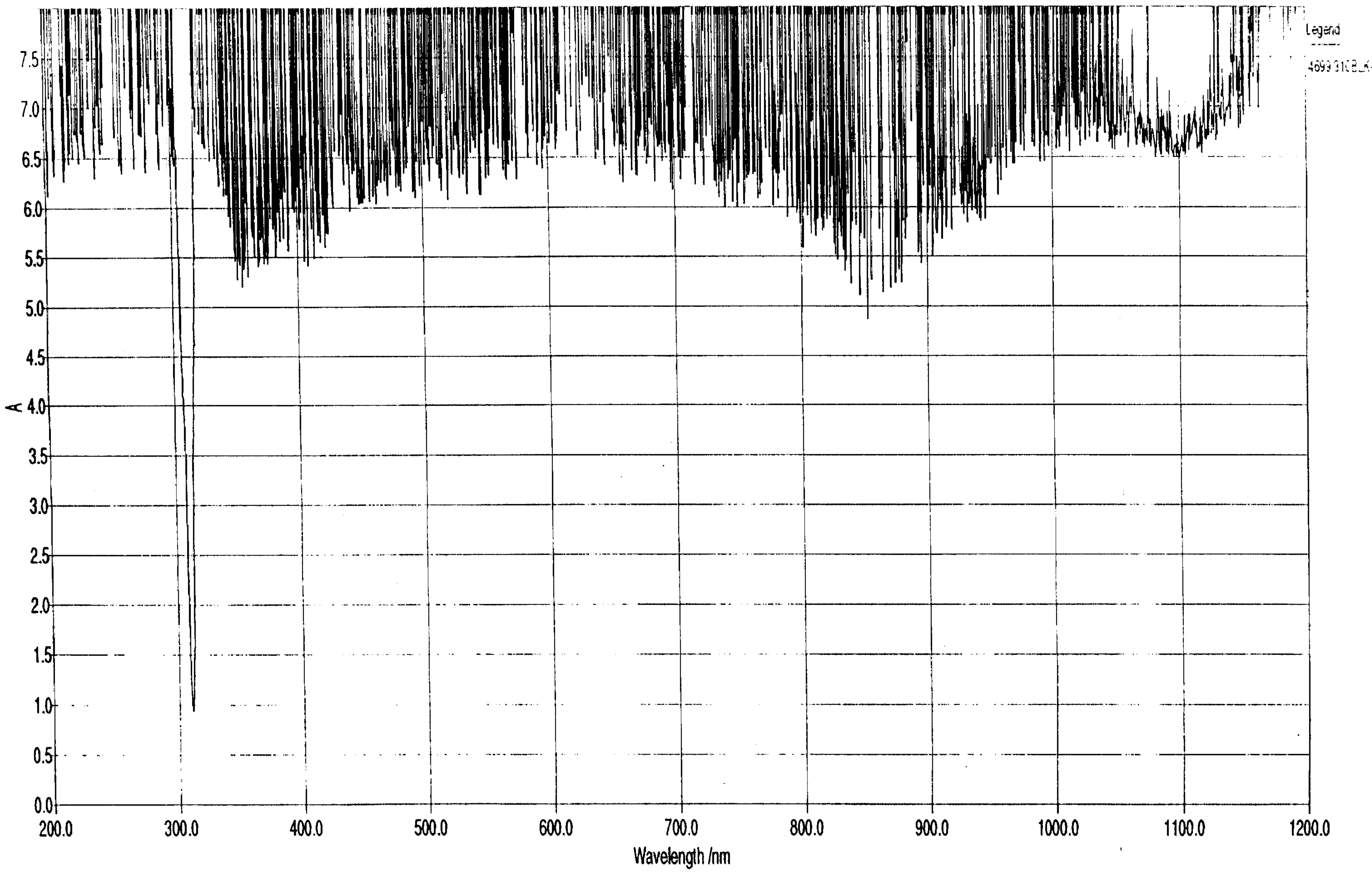
MICROMETER MEASUREMENTS:

width (left to right): 1.299" +/-0.001"
height (purple to silver): 1.299" +/-0.001"



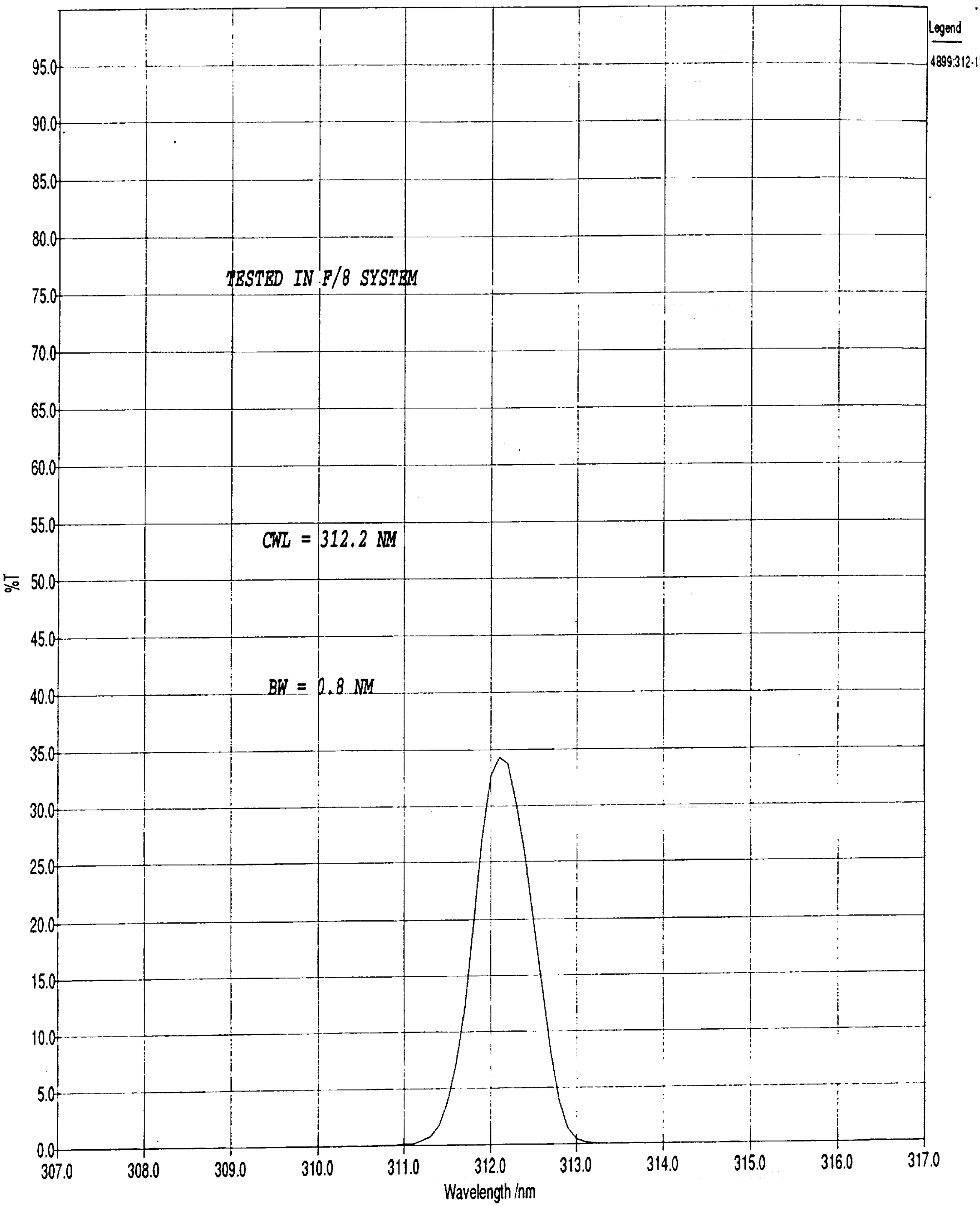
TESTED IN F/8 SYSTEM
CWL = 310.7 NM
BW = 0.8 NM
%T
Wavelength /nm
Legend
4899:310-1

699:310BLK-1

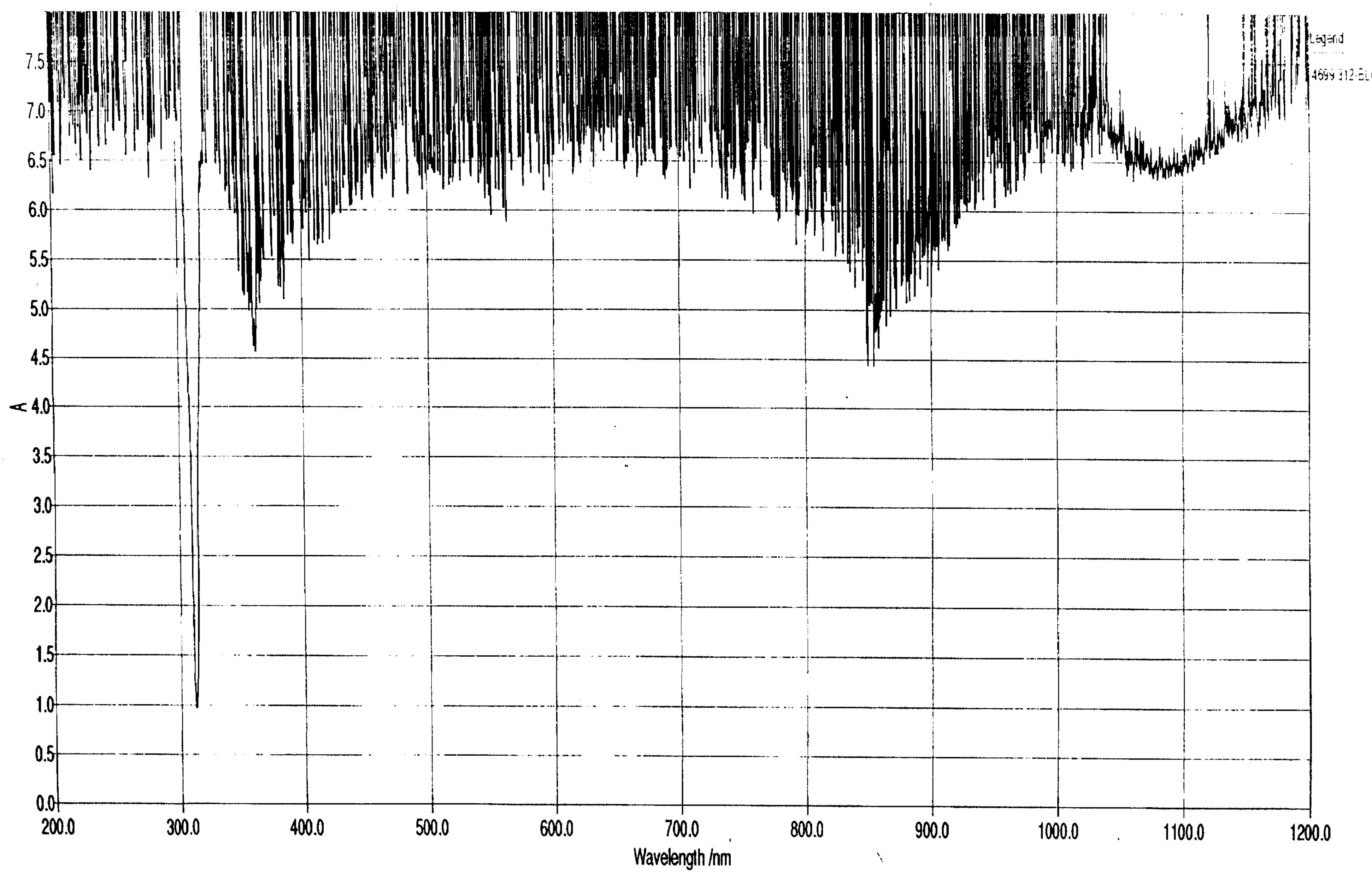


Legend
4699:310BLK-1
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

4899:312-1'

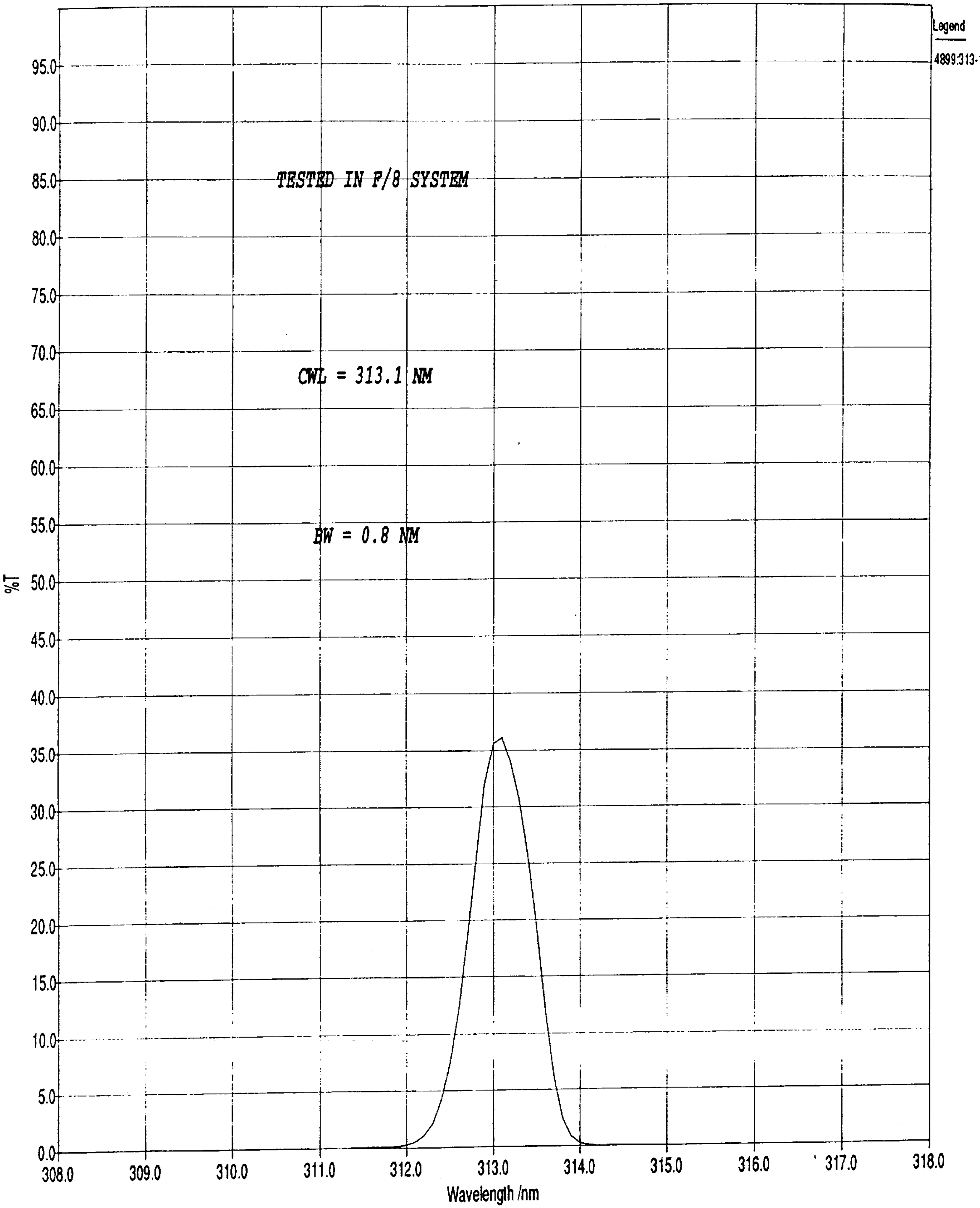

Legend
4899:312-1'
TESTED IN F/8 SYSTEM
CWL = 312.2 NM
BW = 0.8 NM
%T
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
307.0
308.0
309.0
310.0
311.0
312.0
313.0
314.0
315.0
316.0
317.0
Wavelength /nm

4699:312-BLK

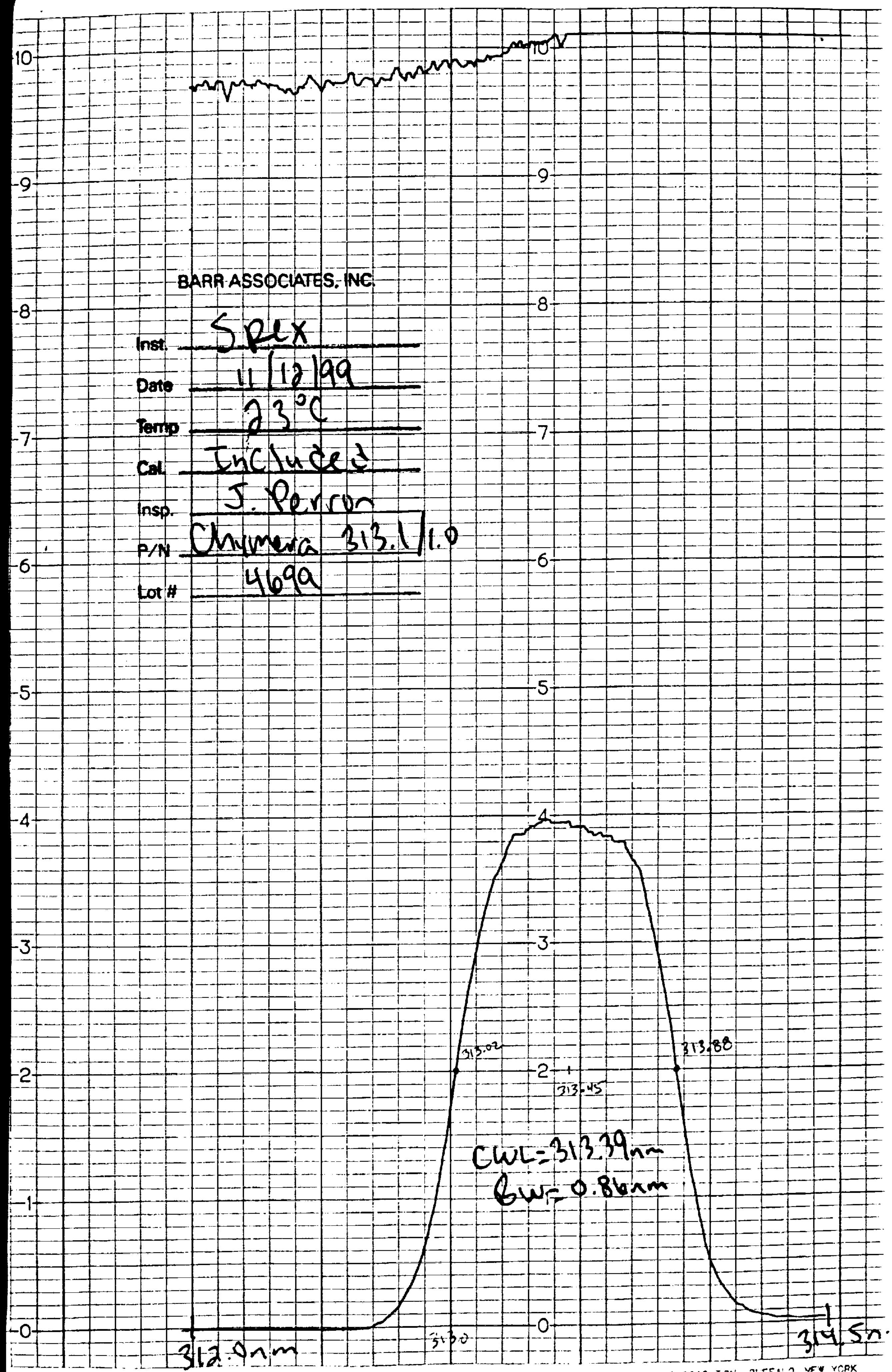


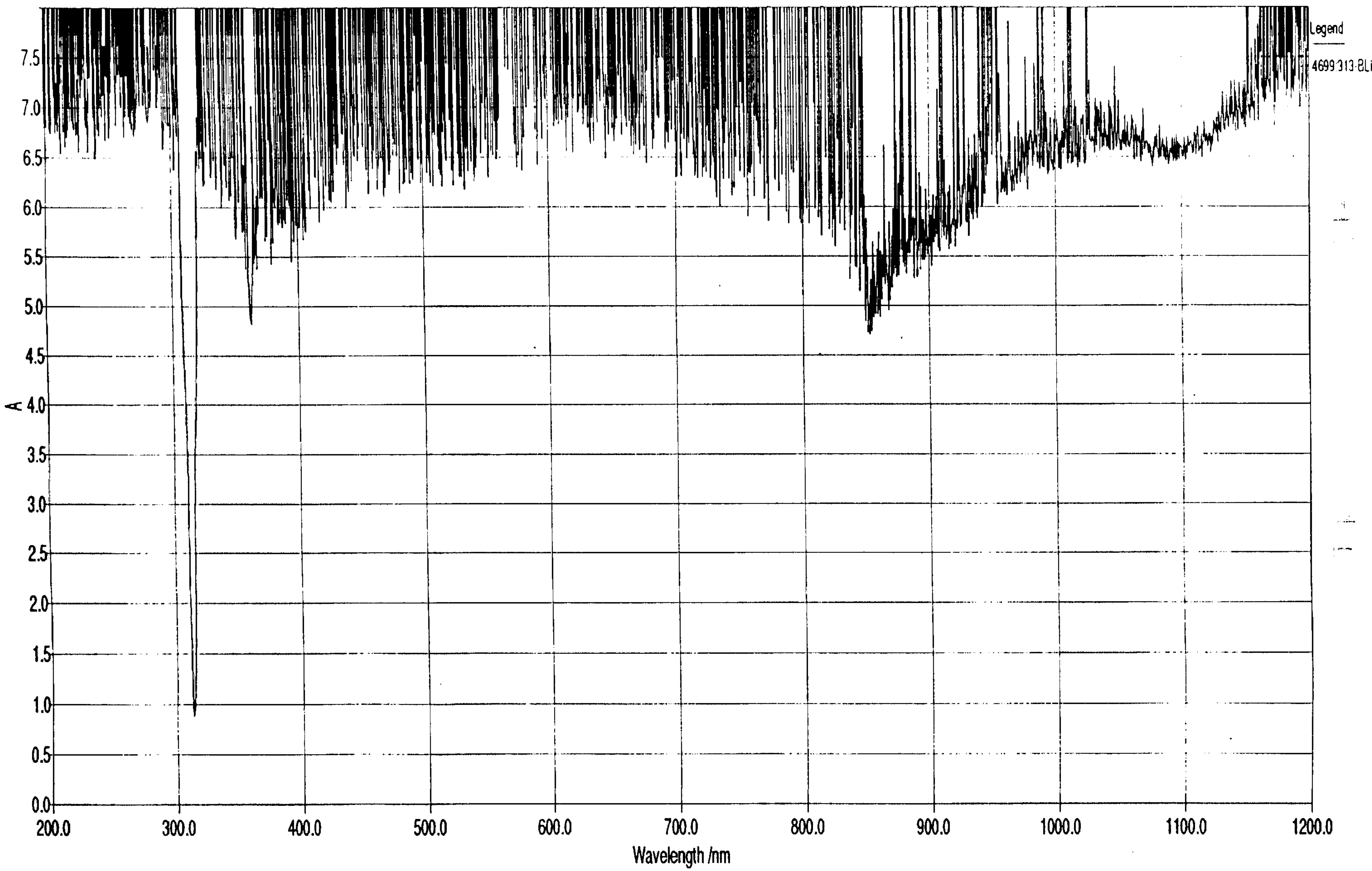
Legend
4699:312-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

4899:313-1



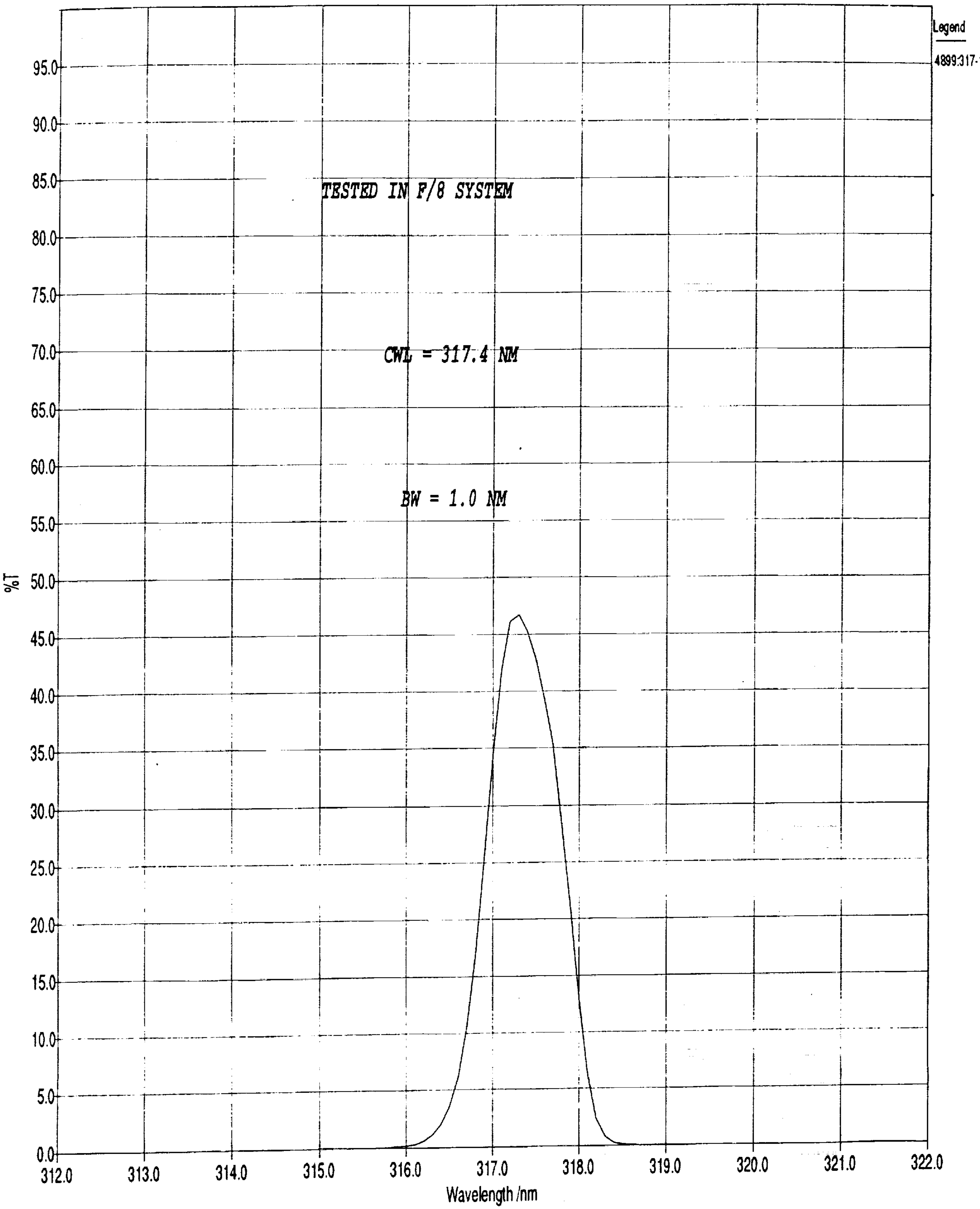
TESTED IN F/8 SYSTEM
CWL = 313.1 NM
BW = 0.8 NM
Legend
4899:313-1
%T
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
308.0
309.0
310.0
311.0
312.0
313.0
314.0
315.0
316.0
317.0
318.0
Wavelength /nm


BARR ASSOCIATES, INC.
Inst. Spex
Date 11/12/99
Temp 23°C
Cal. Included
Insp. J. Perron
P/N Chymera 313.1/1.0
Lot # 4699
10
9
8
7
6
5
4
3
2
1
0
313.02
313.88
313.45
CWL=313.39nm
BW=0.86nm
312.9nm
313.0
314.5n.



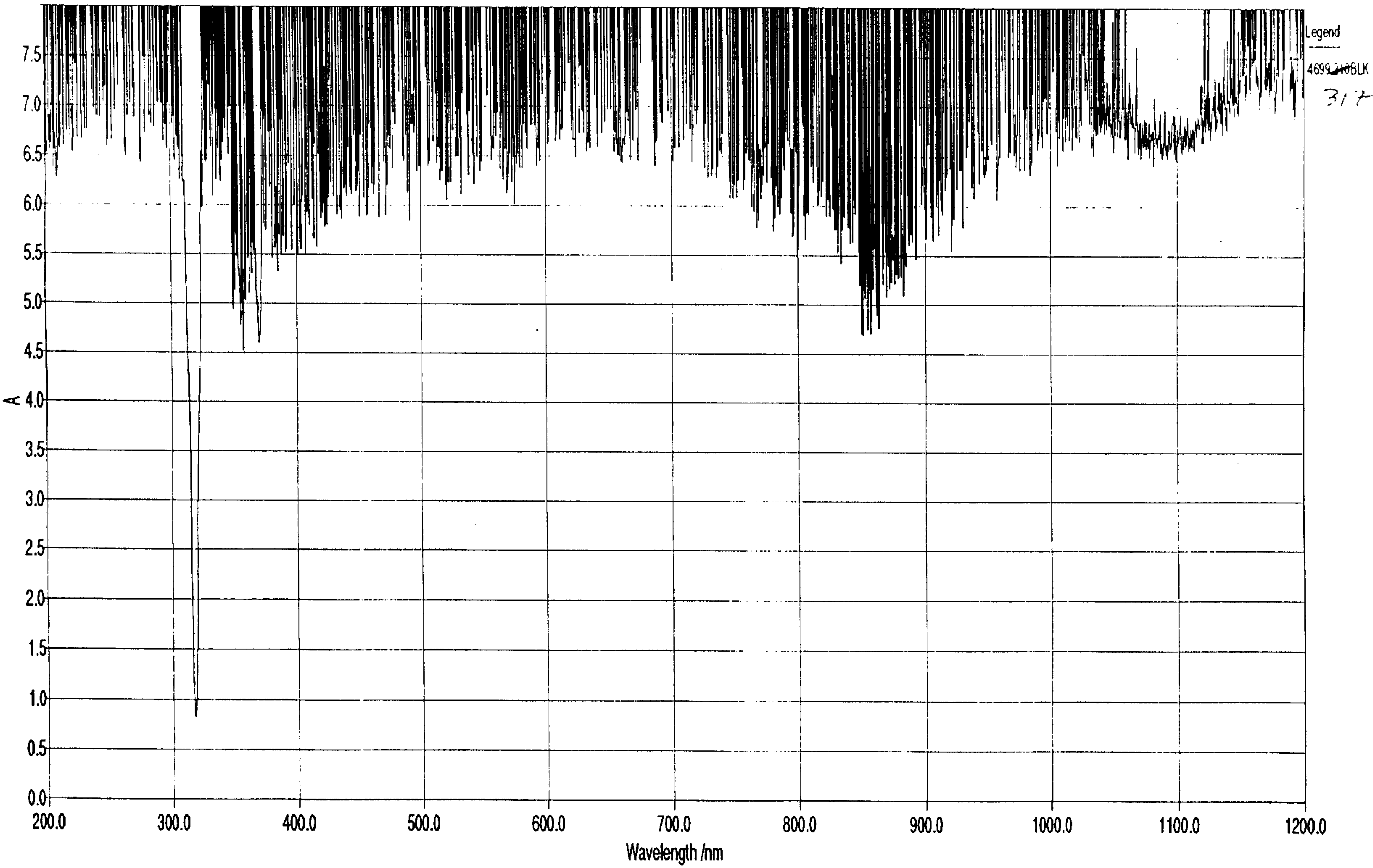
Legend
4699 313-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

4899:317-1



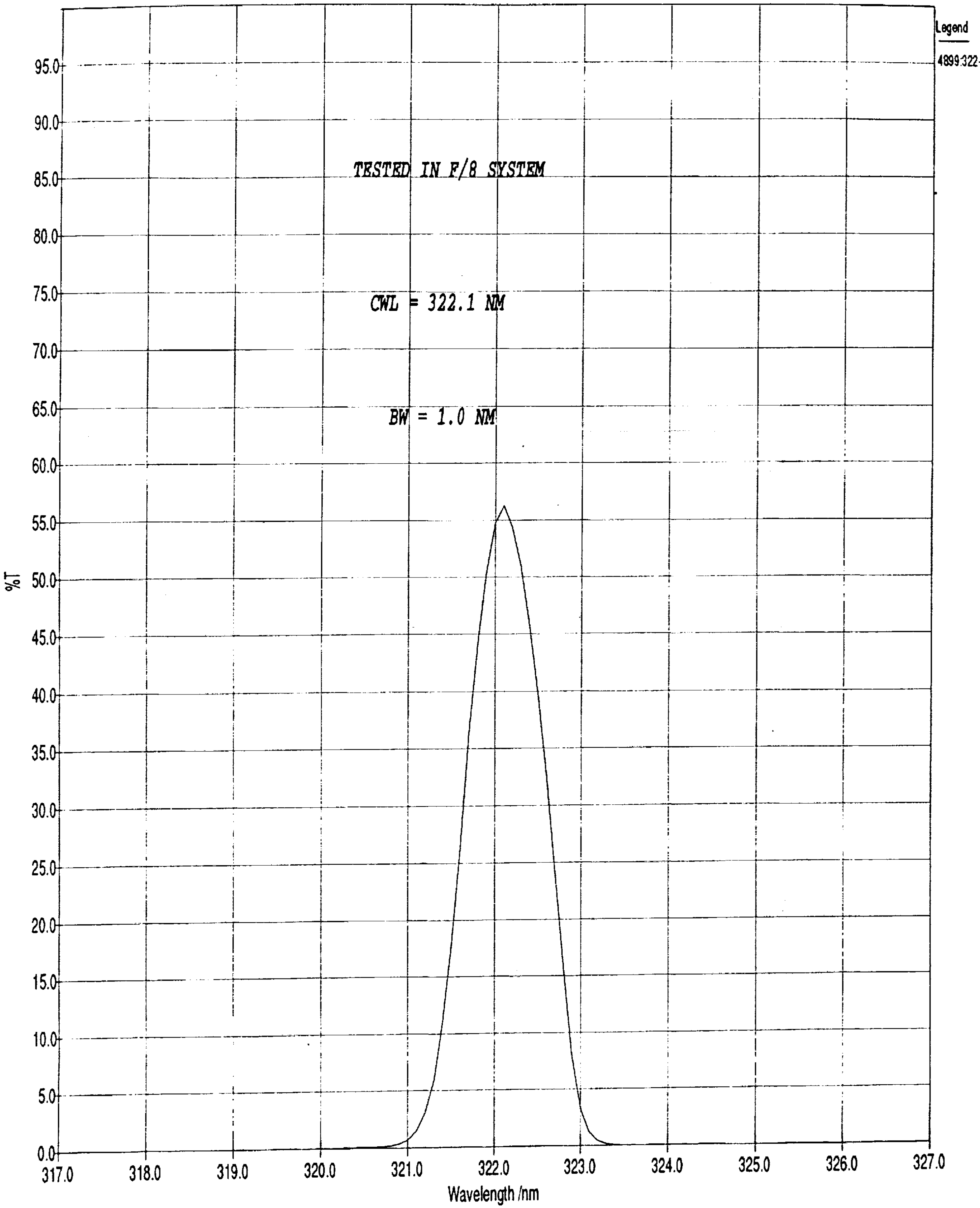
Legend
4899:317-1
TESTED IN F/8 SYSTEM
CWL = 317.4 NM
BW = 1.0 NM
%T
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
312.0
313.0
314.0
315.0
316.0
317.0
318.0
319.0
320.0
321.0
322.0
Wavelength /nm

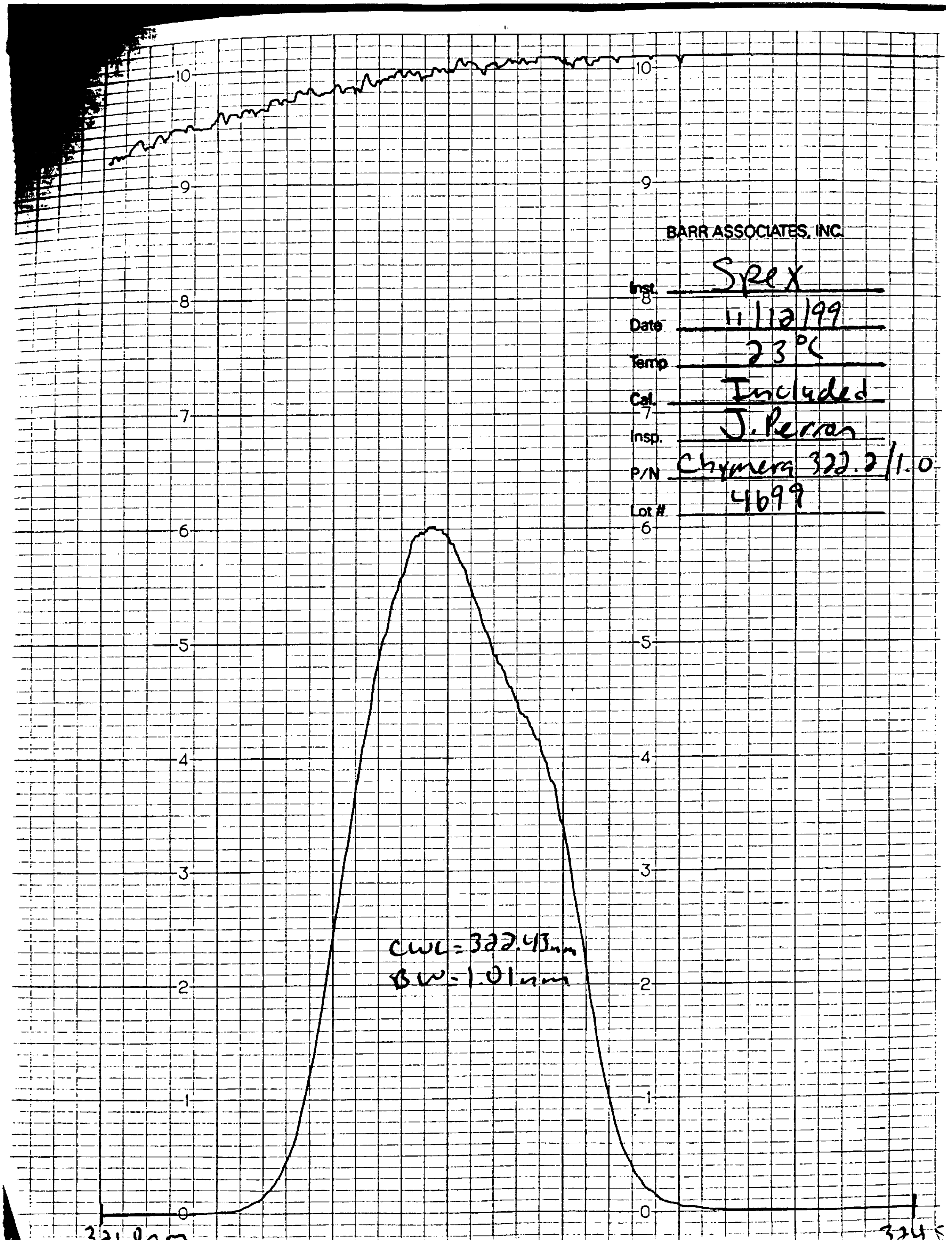
99:310BLK



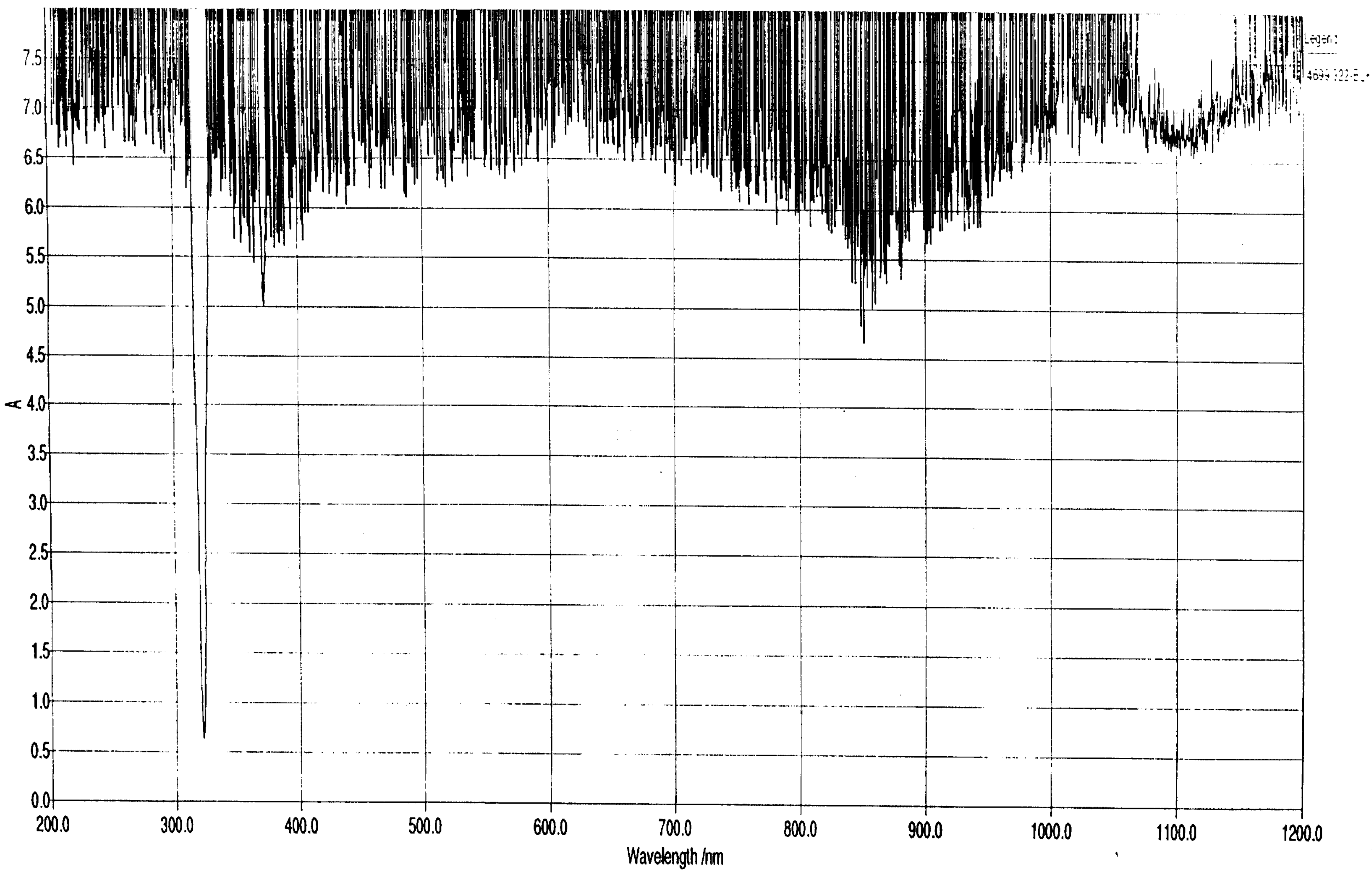
Legend
4699 310BLK
317
7.5
7.0
6.5
6.0
5.5
5.0
4.5
A
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

4899:322-1

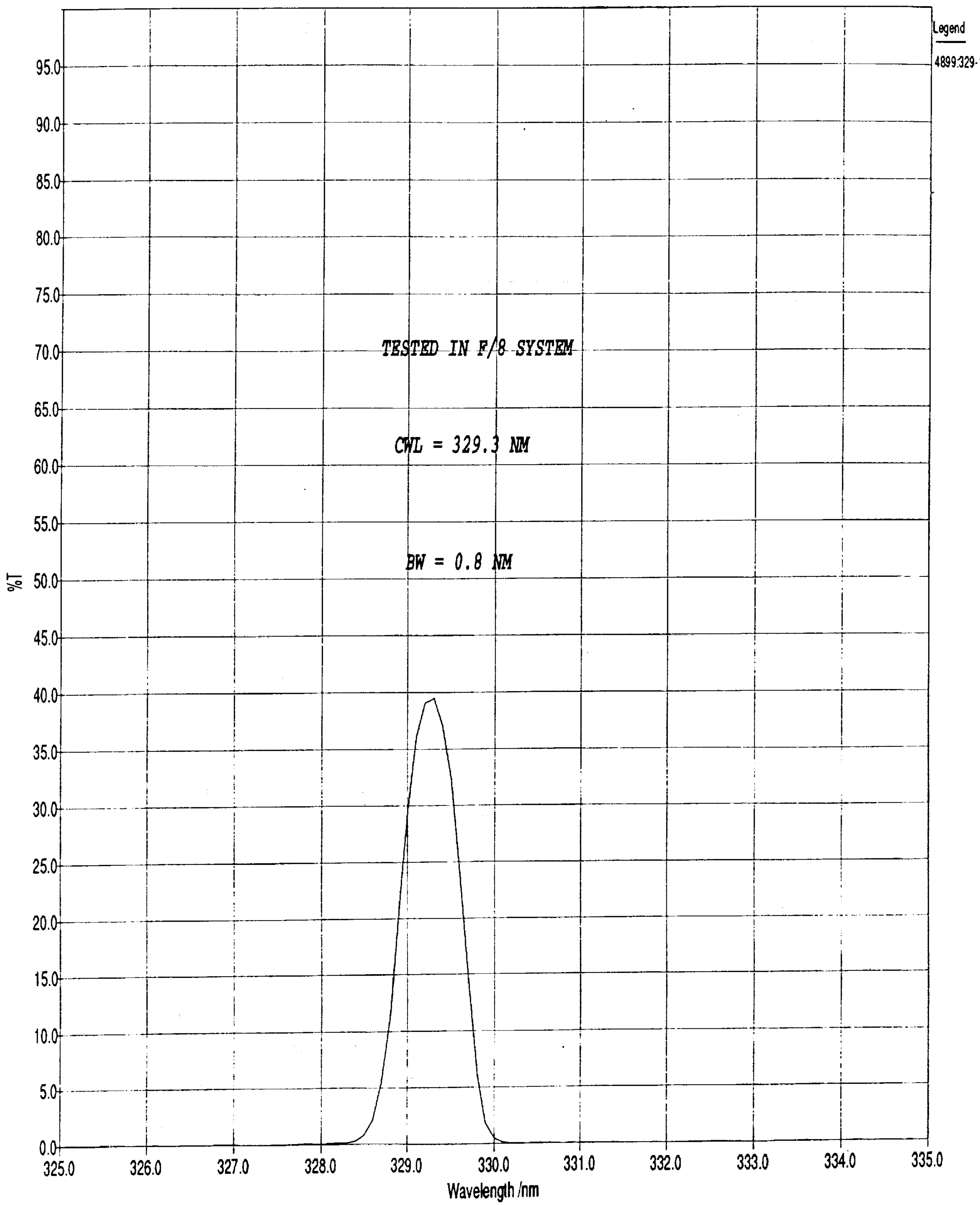

Legend
4899:322-1
TESTED IN F/8 SYSTEM
CWL = 322.1 NM
BW = 1.0 NM
%T
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
317.0
318.0
319.0
320.0
321.0
322.0
323.0
324.0
325.0
326.0
327.0
Wavelength /nm


10
9
8
7
6
5
4
3
2
1
0
BARR ASSOCIATES, INC.
Inst. Spex
Date 11/12/99
Temp 23 °C
Cal. Included
Insp. J. Perran
P/N Chymera 322.2/1.0
Lot # 4699
CWL = 322.43 nm
BW = 1.01 nm

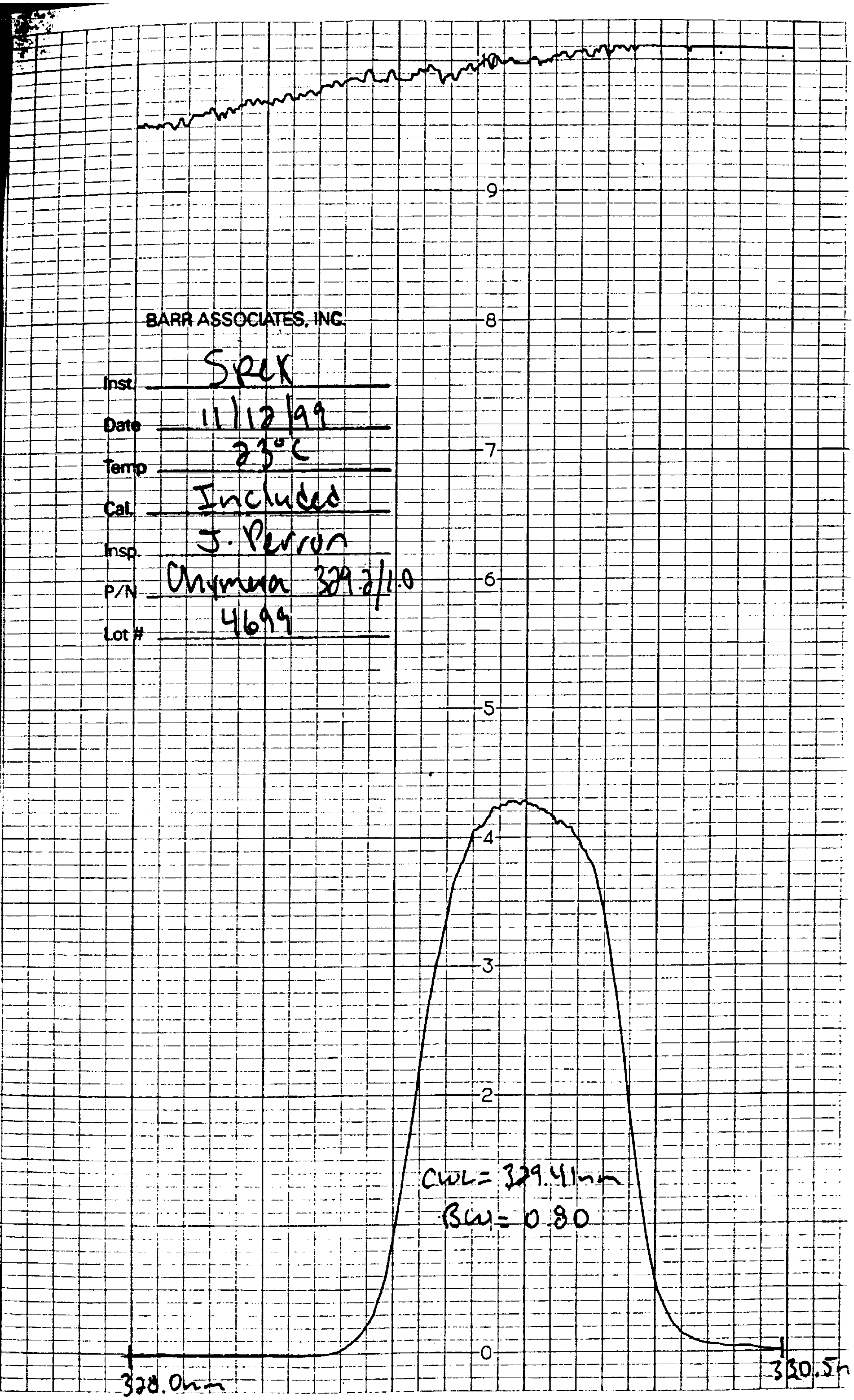
4699:322-BLK1



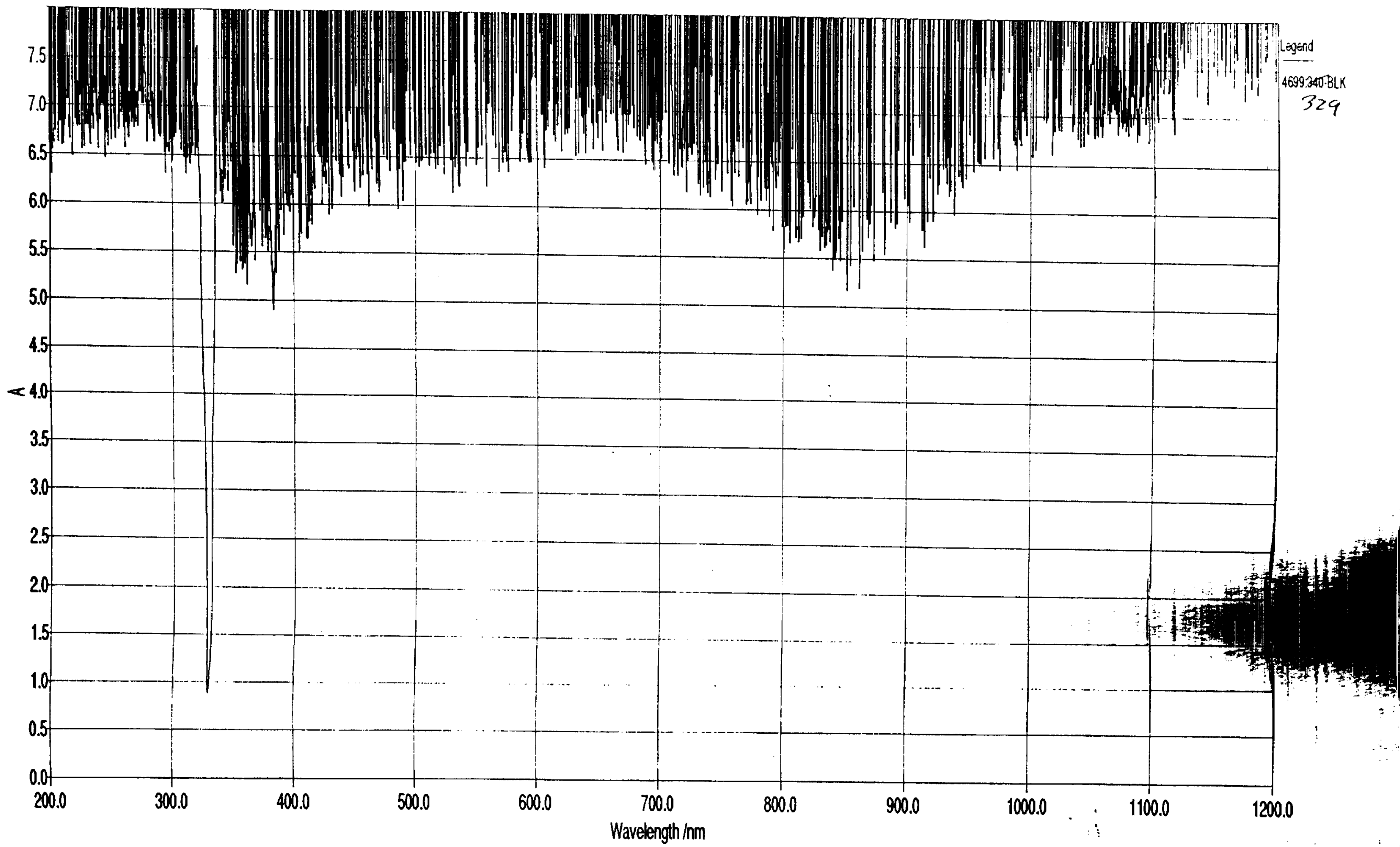
4899:329-1



Legend
4899:329-1
TESTED IN F/8 SYSTEM
CWL = 329.3 NM
BW = 0.8 NM
%T
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
325.0
326.0
327.0
328.0
329.0
330.0
331.0
332.0
333.0
334.0
335.0
Wavelength /nm

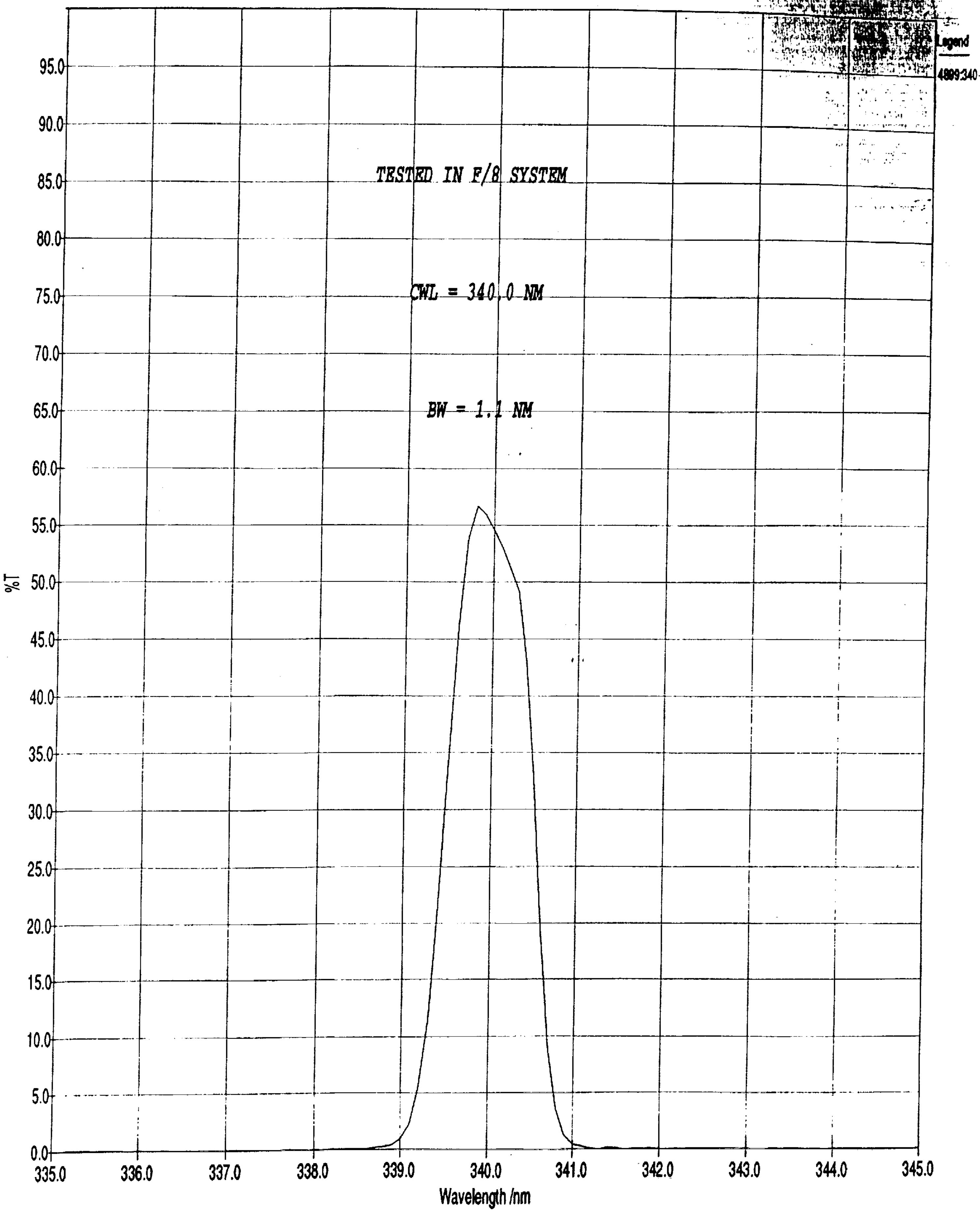

BARR ASSOCIATES, INC.
Inst. Spex
Date 11/12/99
Temp 23°C
Cal. Included
Insp. J. Perron
P/N Olympia 329.2/1.0
Lot # 4699
10
9
8
7
6
5
4
3
2
0
CWL = 329.41nm
BW = 0.80
328.0nm
330.5nm

4699:340-BLK

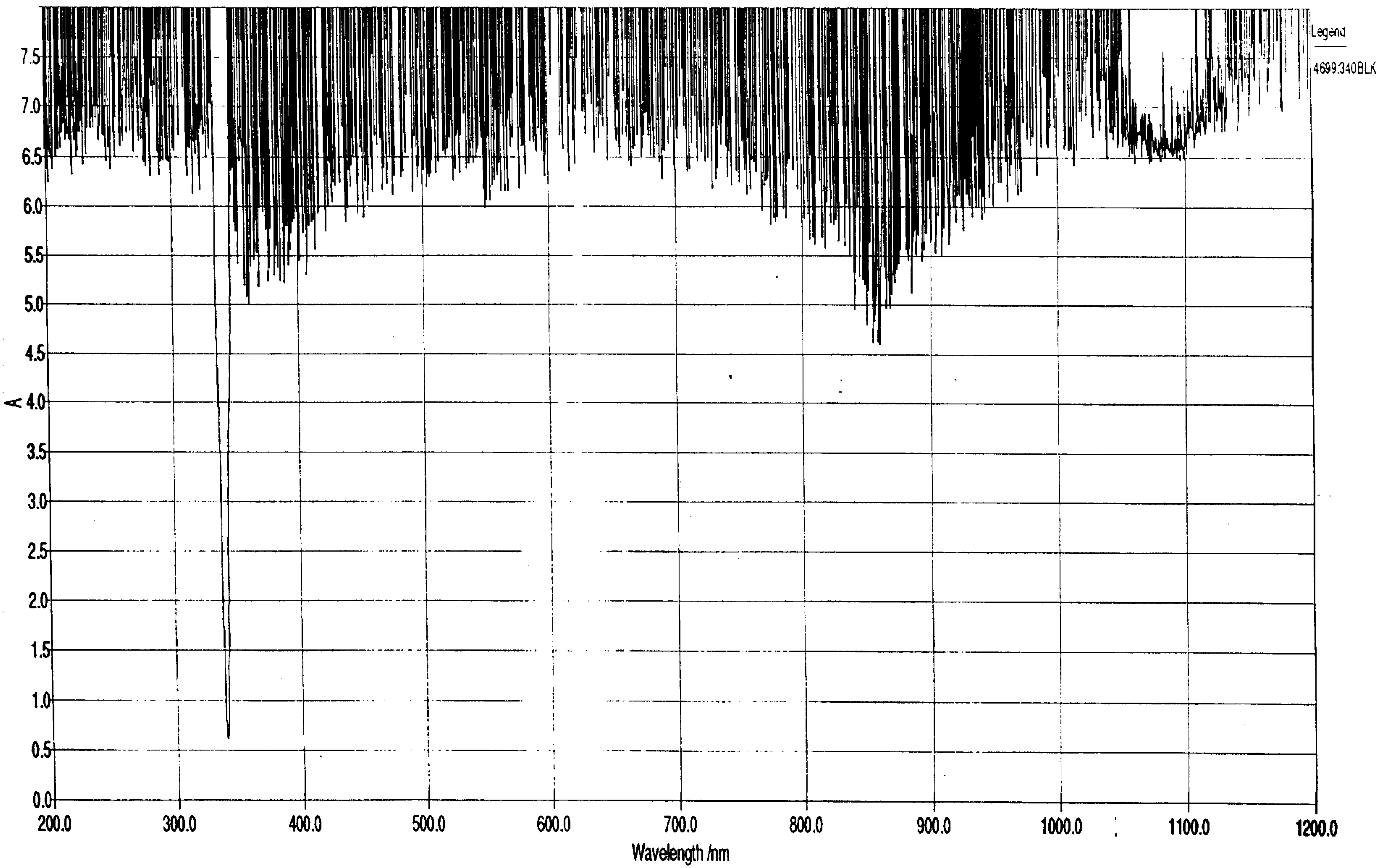


Legend
4699:340-BLK
329
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

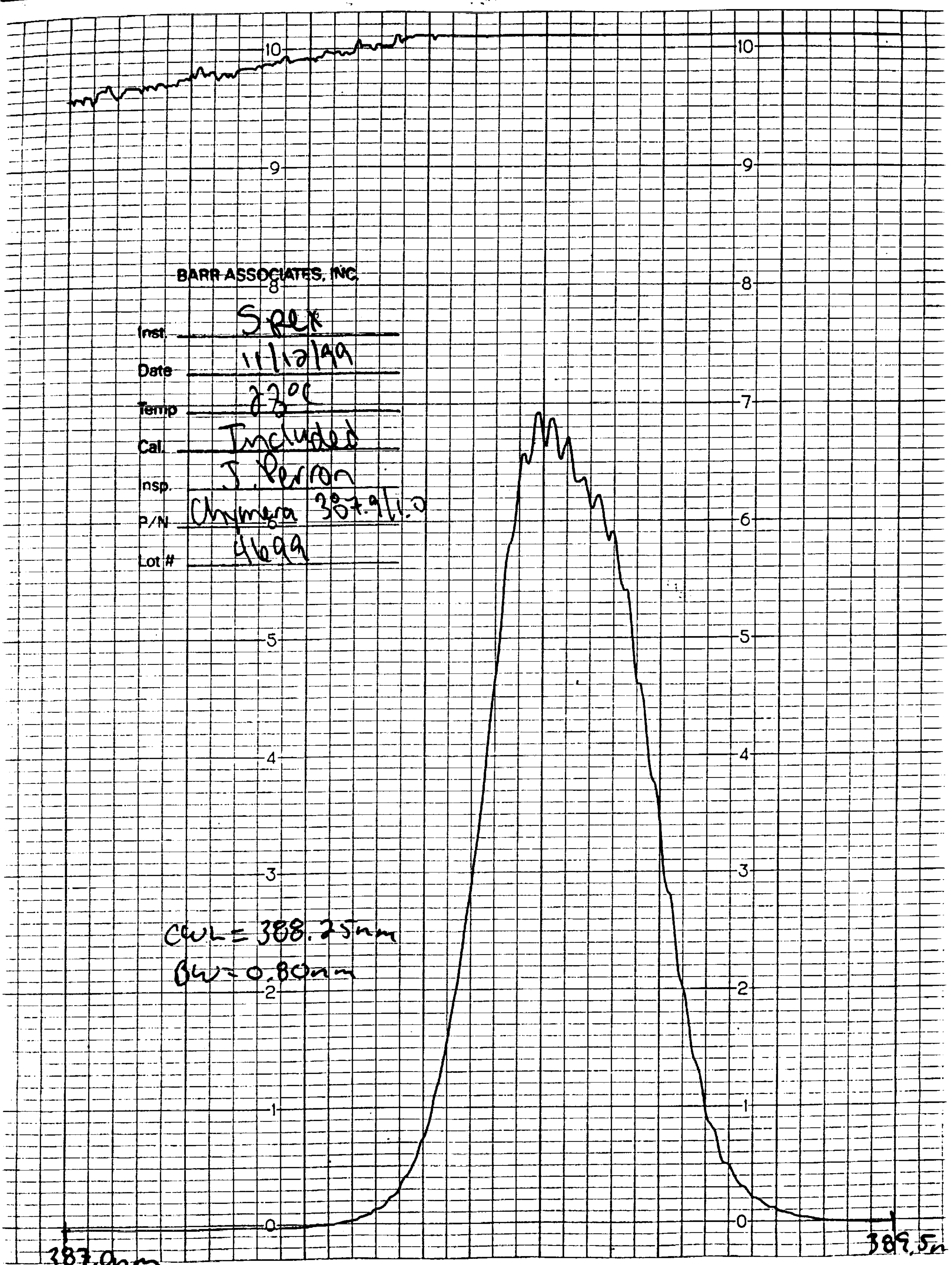
4899:340-1


TESTED IN F/8 SYSTEM
CWL = 340.0 NM
BW = 1.1 NM
%T
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
335.0
336.0
337.0
338.0
339.0
340.0
341.0
342.0
343.0
344.0
345.0
Wavelength /nm
Legend
4899:340

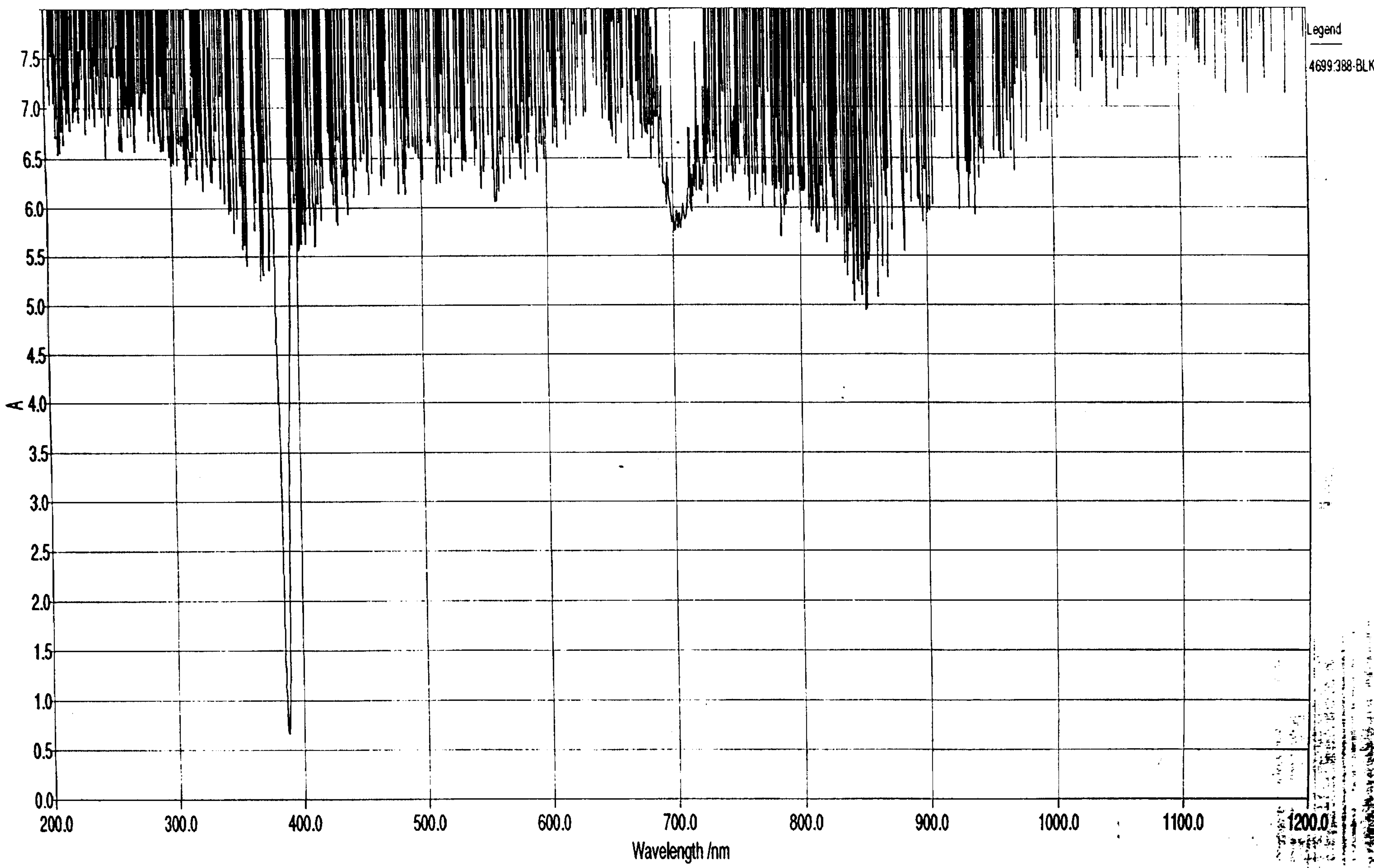
4699:340BLK



Legend
4699:340BLK
7.5
7.0
6.5
6.0
5.5
5.0
4.5
A 4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

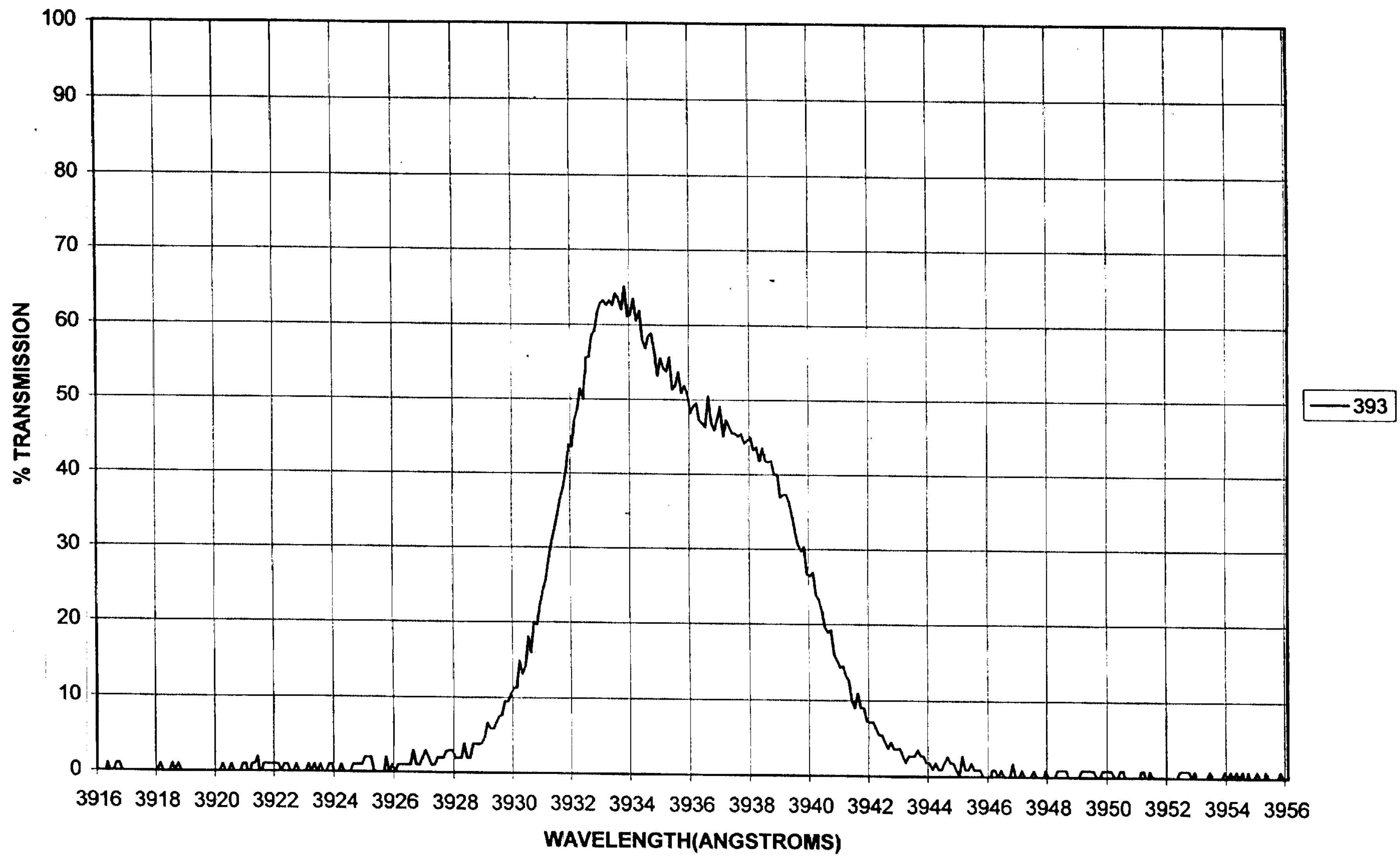

BARR ASSOCIATES, INC.
Inst. Spex
Date 11/12/99
Temp 23°C
Cal. Included
Insp. J. Perron
P/N Chymera 387.9/1.0
Lot # 4699
CWL = 388.25nm
BW = 0.80nm
387.0nm
389.5nm

4699:388-BLK

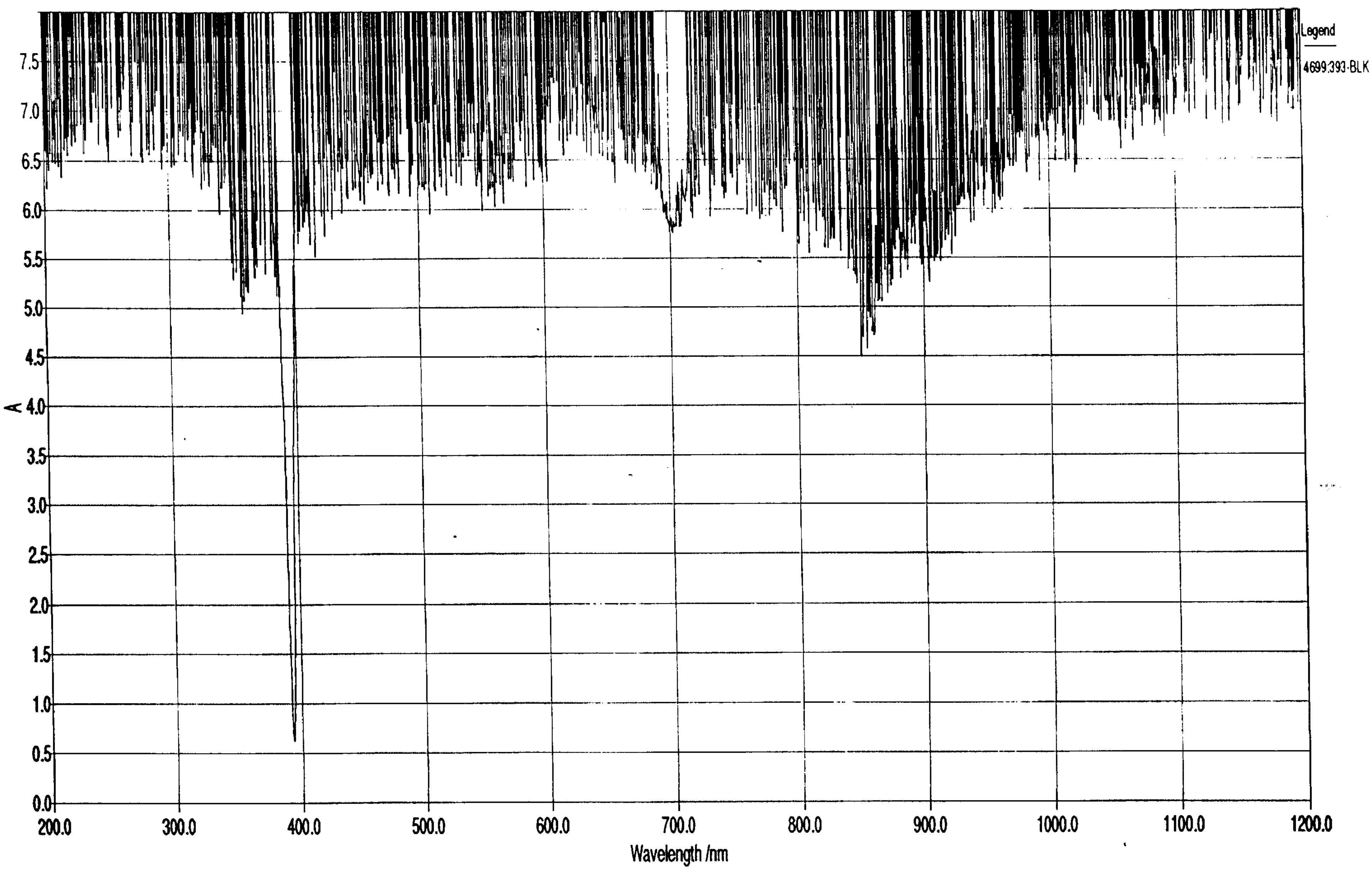


Legend
4699:388-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

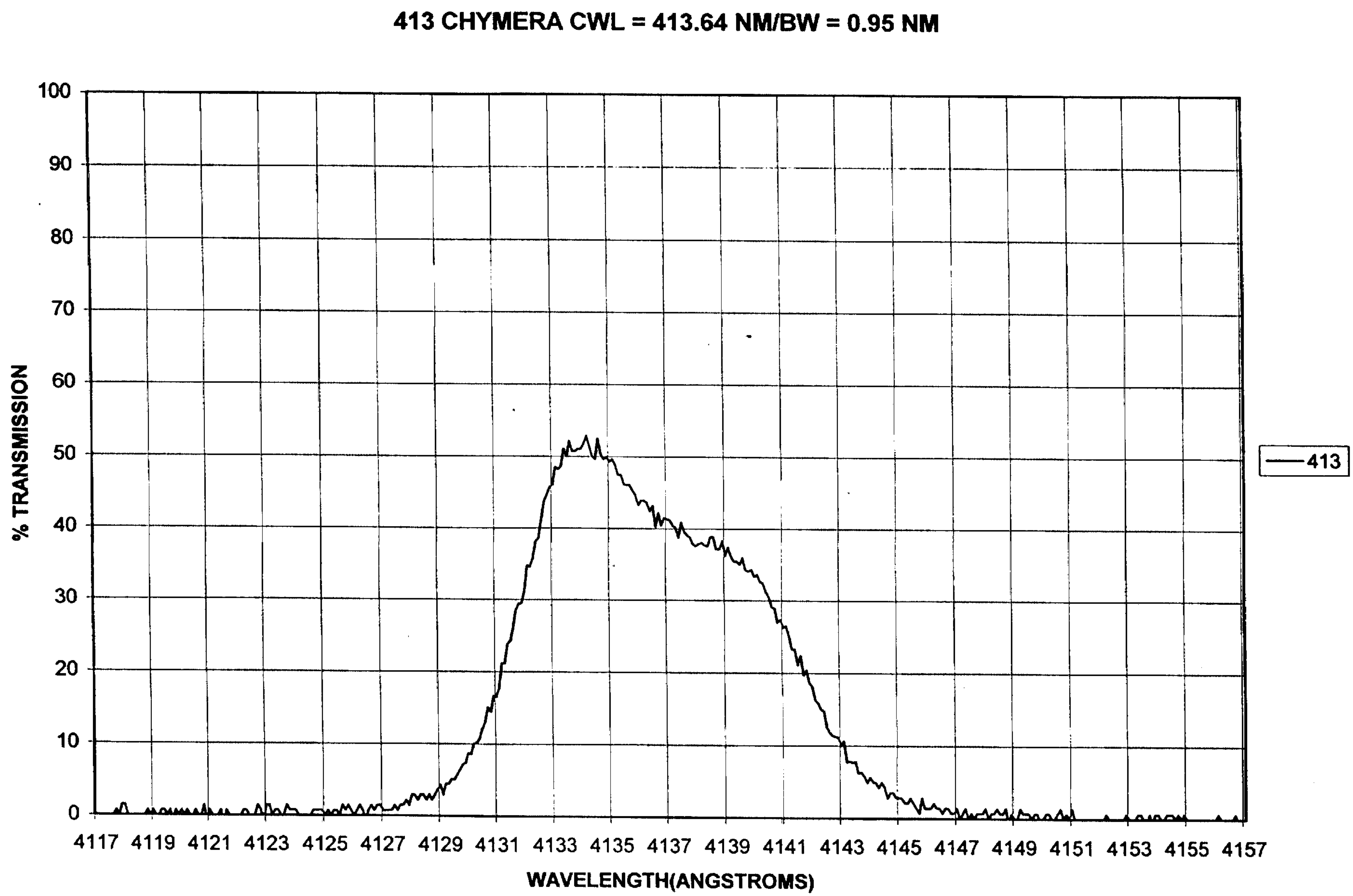
393 CHYMERA CWL = 393.56 NM/BW = 0.81 NM



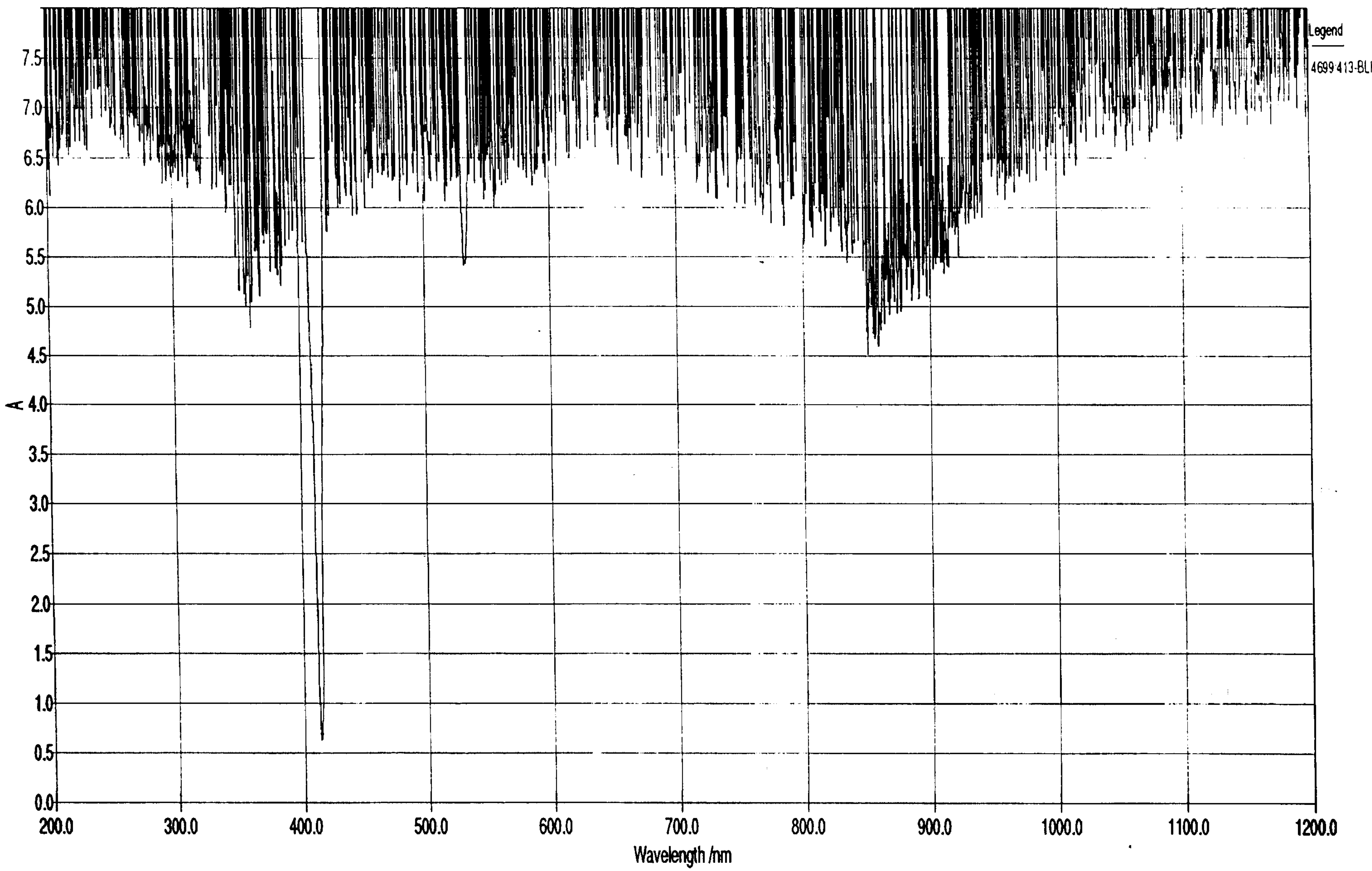
4699:393-BLK



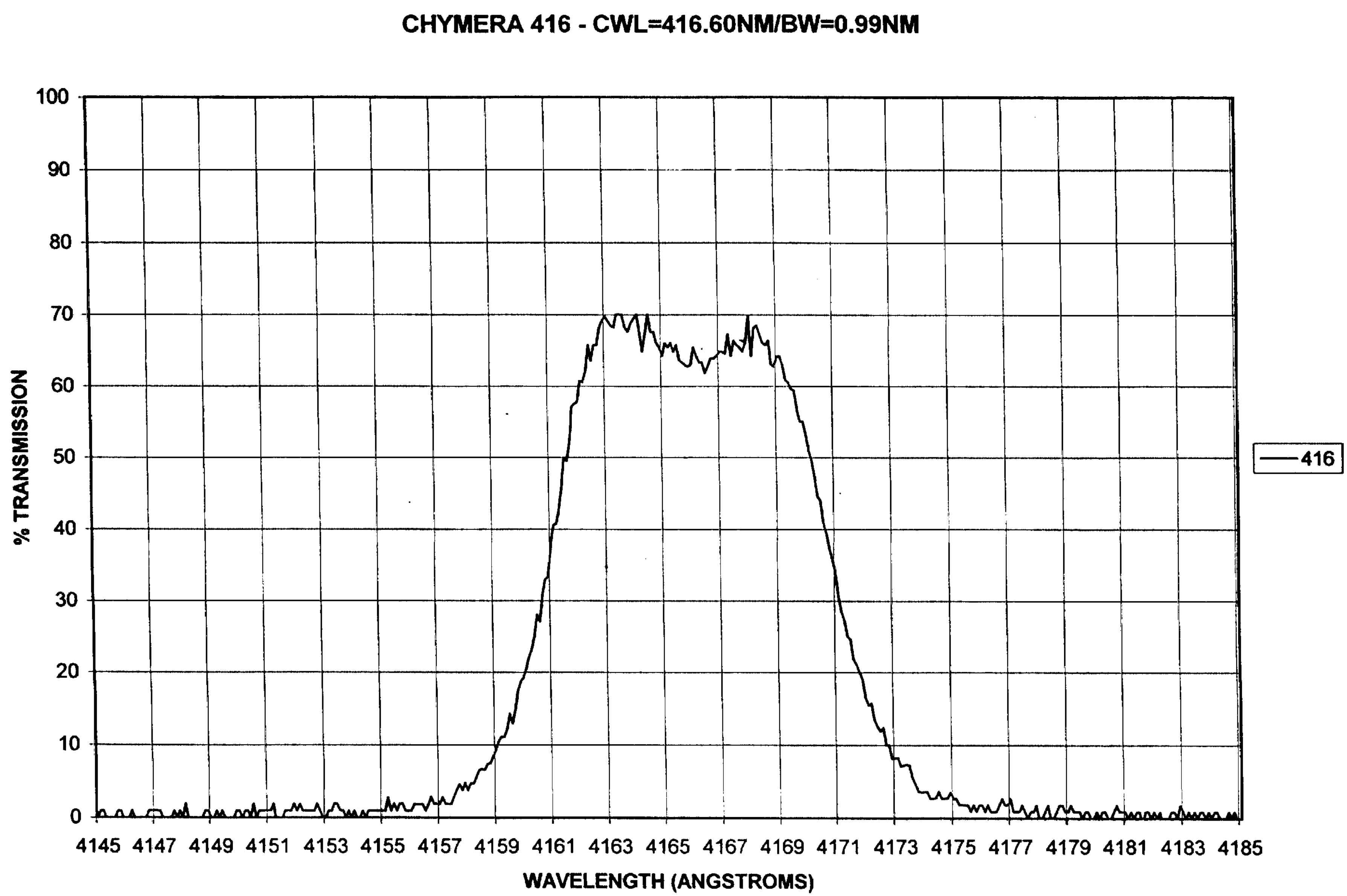
Legend
4699:393-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm


413 CHYMERA CWL = 413.64 NM/BW = 0.95 NM
% TRANSMISSION
100
90
80
70
60
50
40
30
20
10
0
4117 4119 4121 4123 4125 4127 4129 4131 4133 4135 4137 4139 4141 4143 4145 4147 4149 4151 4153 4155 4157
WAVELENGTH(ANGSTROMS)
413

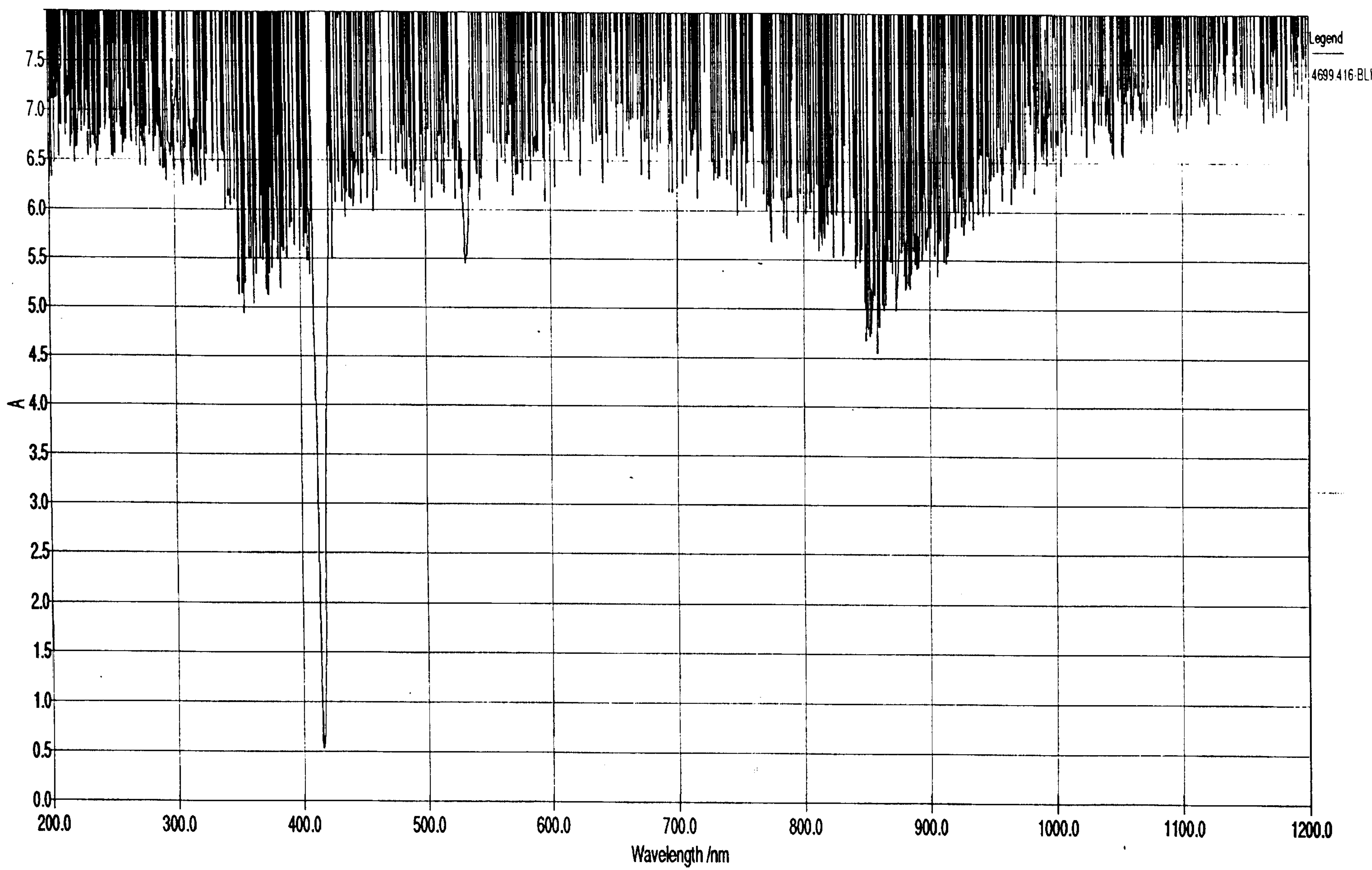
4699:413-BLK



Legend
4699:413-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

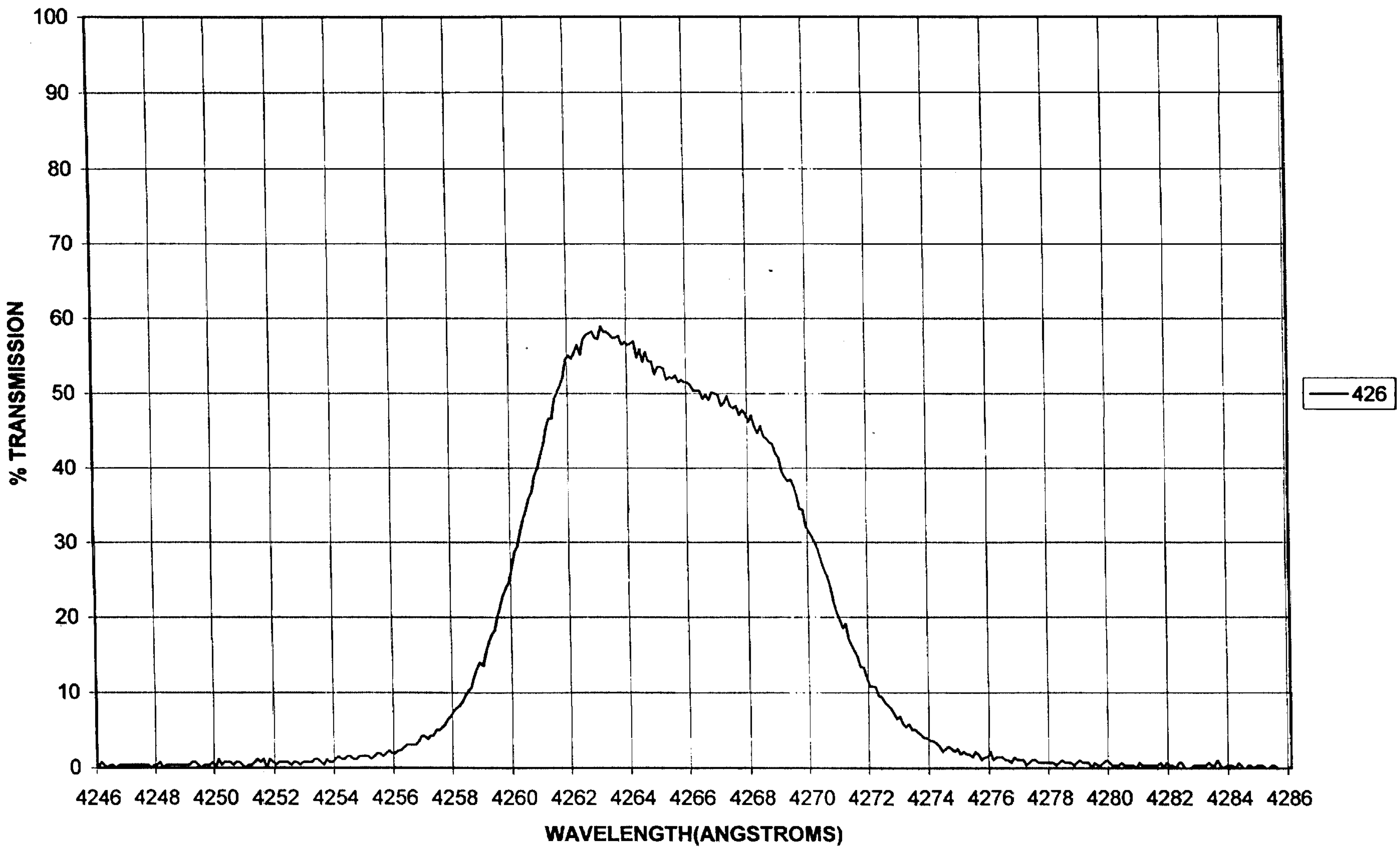

CHYMERA 416 - CWL=416.60NM/BW=0.99NM
% TRANSMISSION
100
90
80
70
60
50
40
30
20
10
0
4145 4147 4149 4151 4153 4155 4157 4159 4161 4163 4165 4167 4169 4171 4173 4175 4177 4179 4181 4183 4185
WAVELENGTH (ANGSTROMS)
416

4699:416-BLK

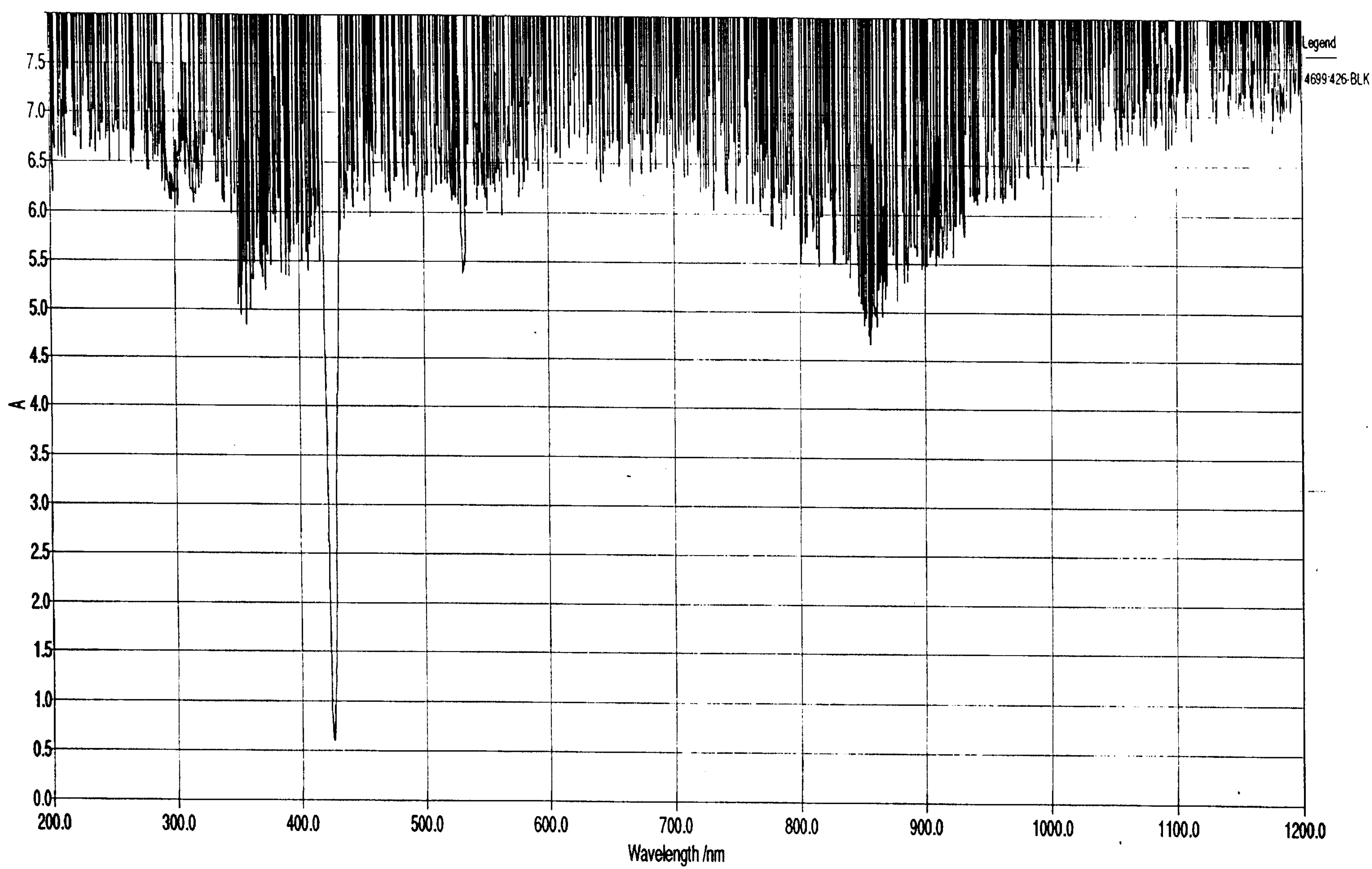


Legend
4699.416-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

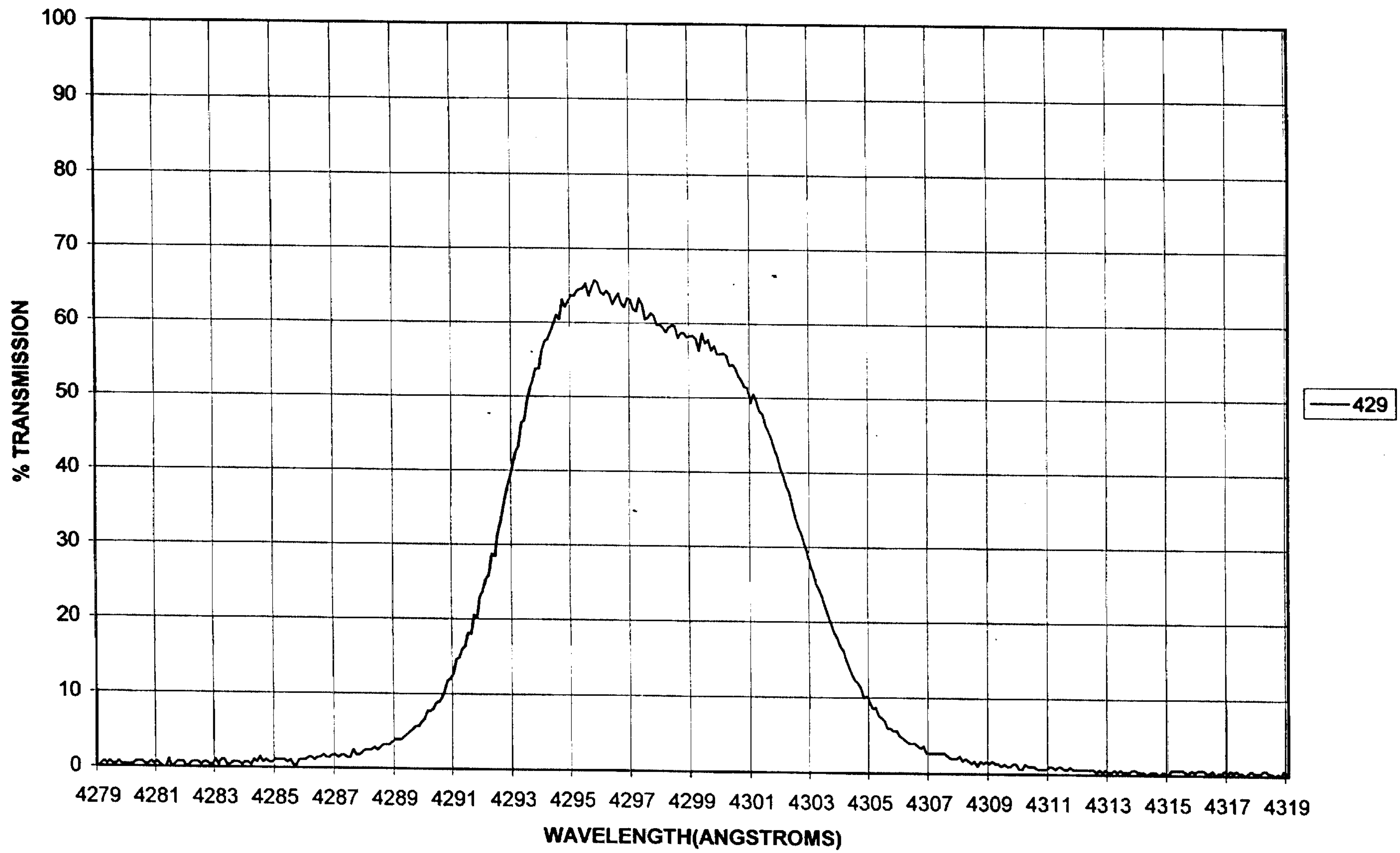
426 CHYMERA CWL = 426.53 NM/BW = 1.01 NM



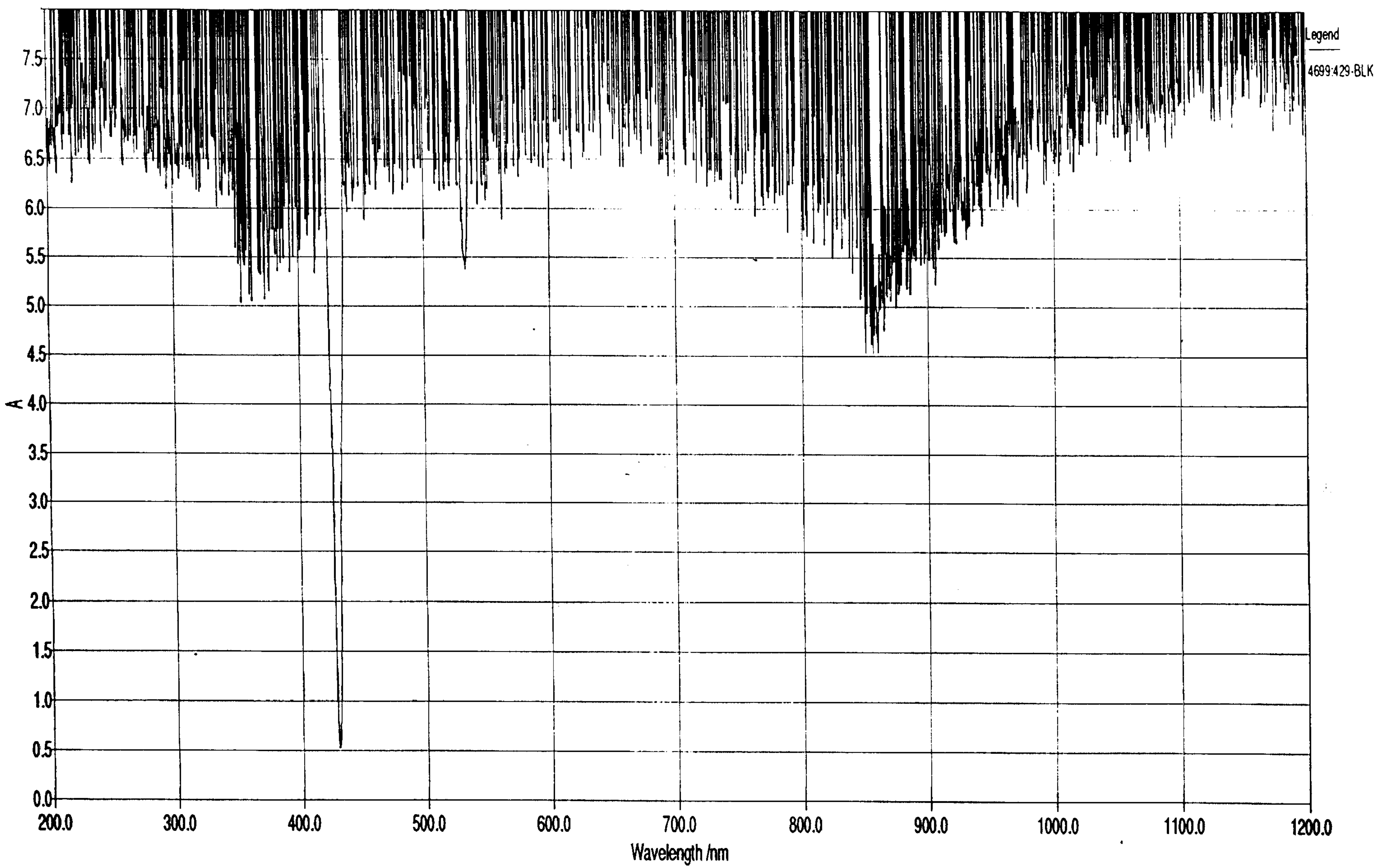
4699:426-BLK



429 CHYMERA CWL = 429.76 NM/BW = 1.00 NM

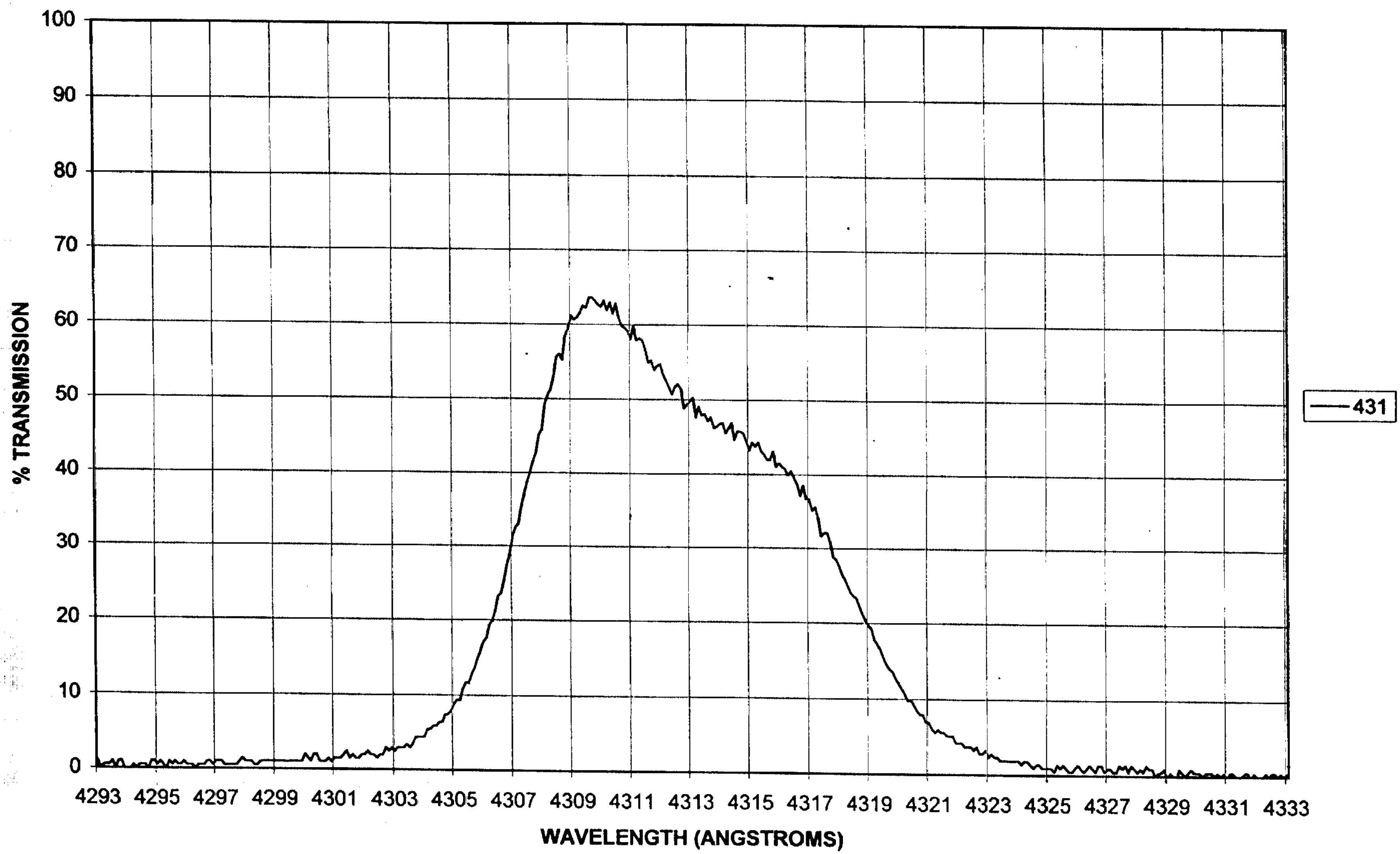


4699:429-BLK

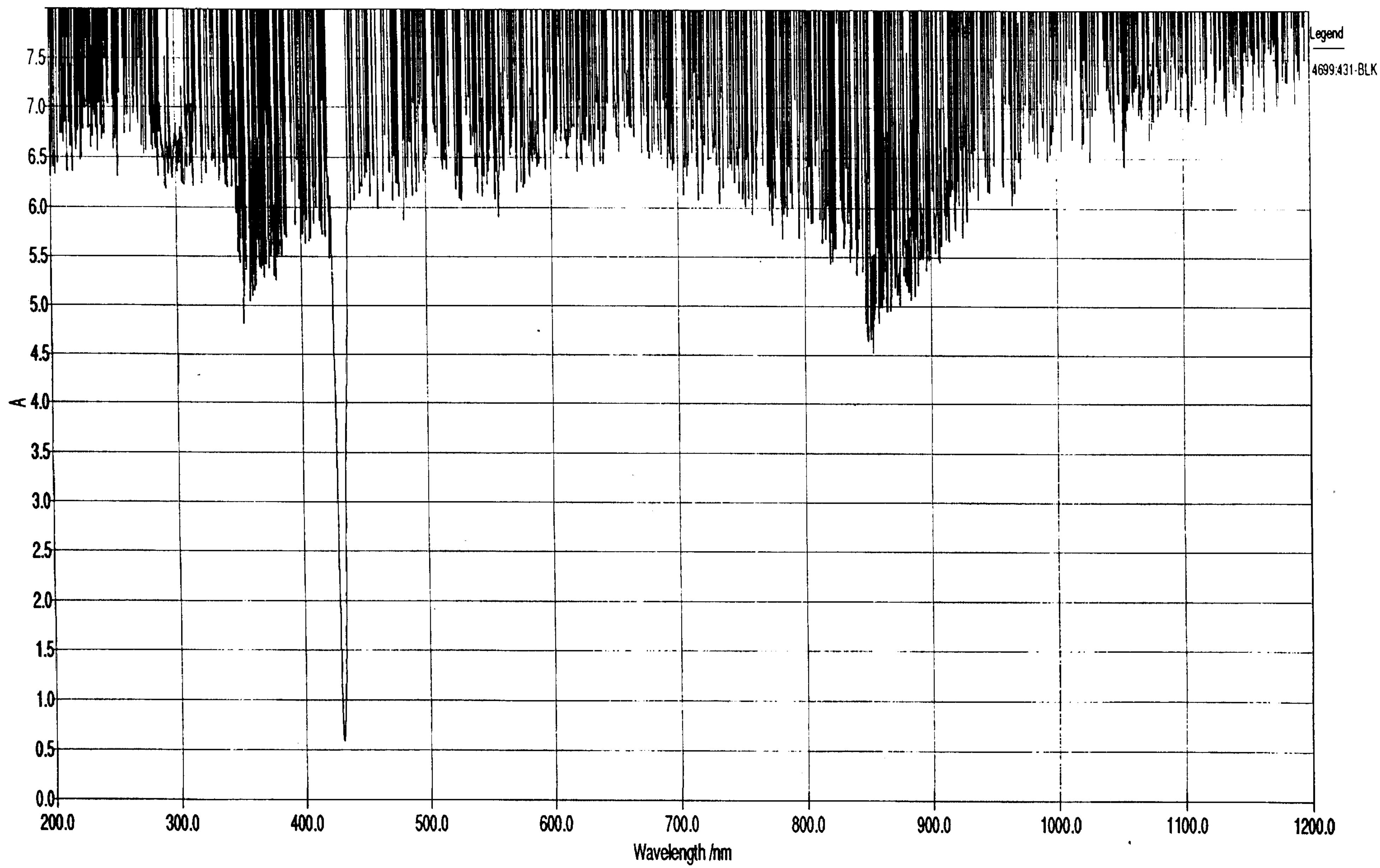


Legend
4699:429-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

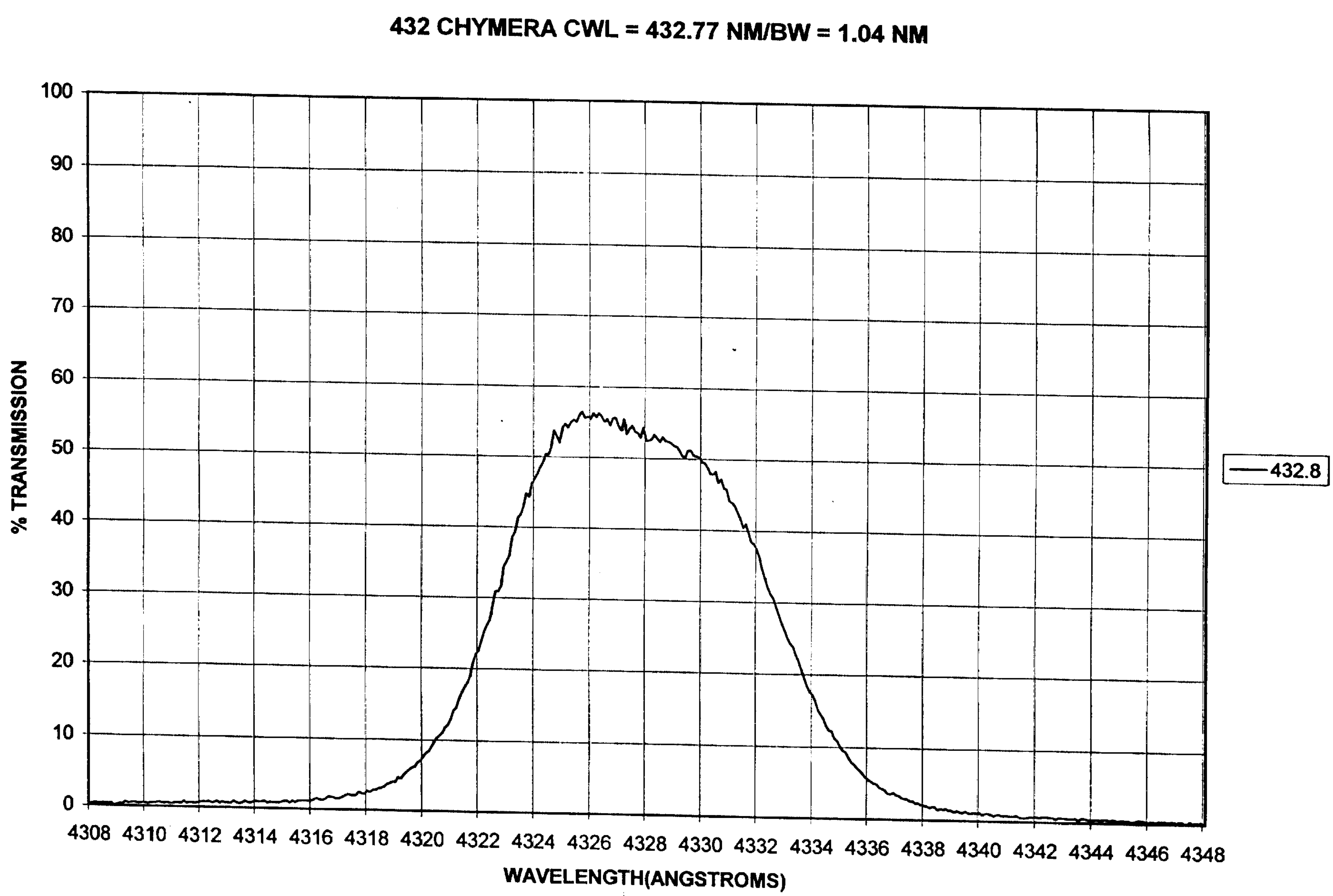
CHYMERA 431 - CWL=431.24NM/BW=1.06NM



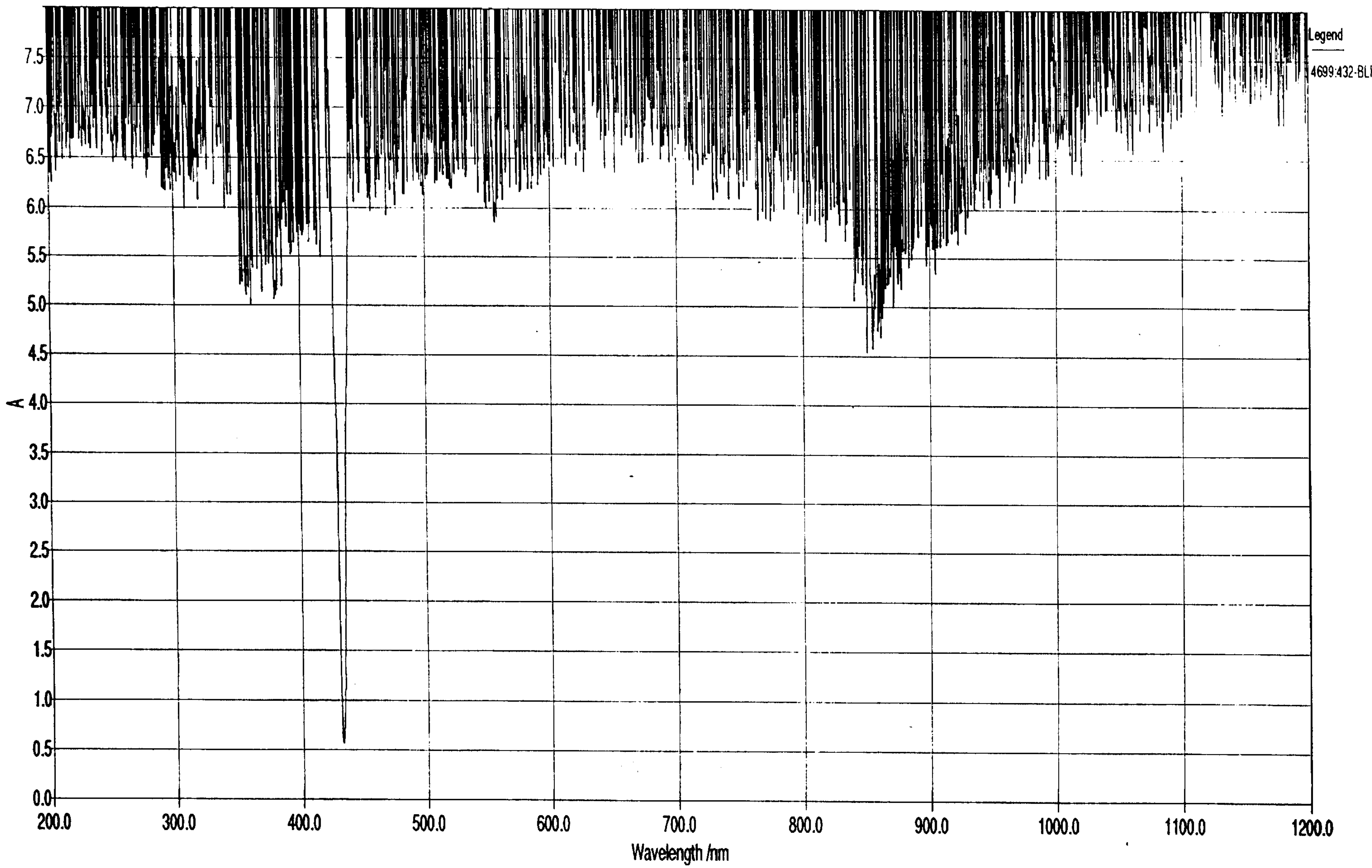
4699:431-BLK



Legend
4699:431-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

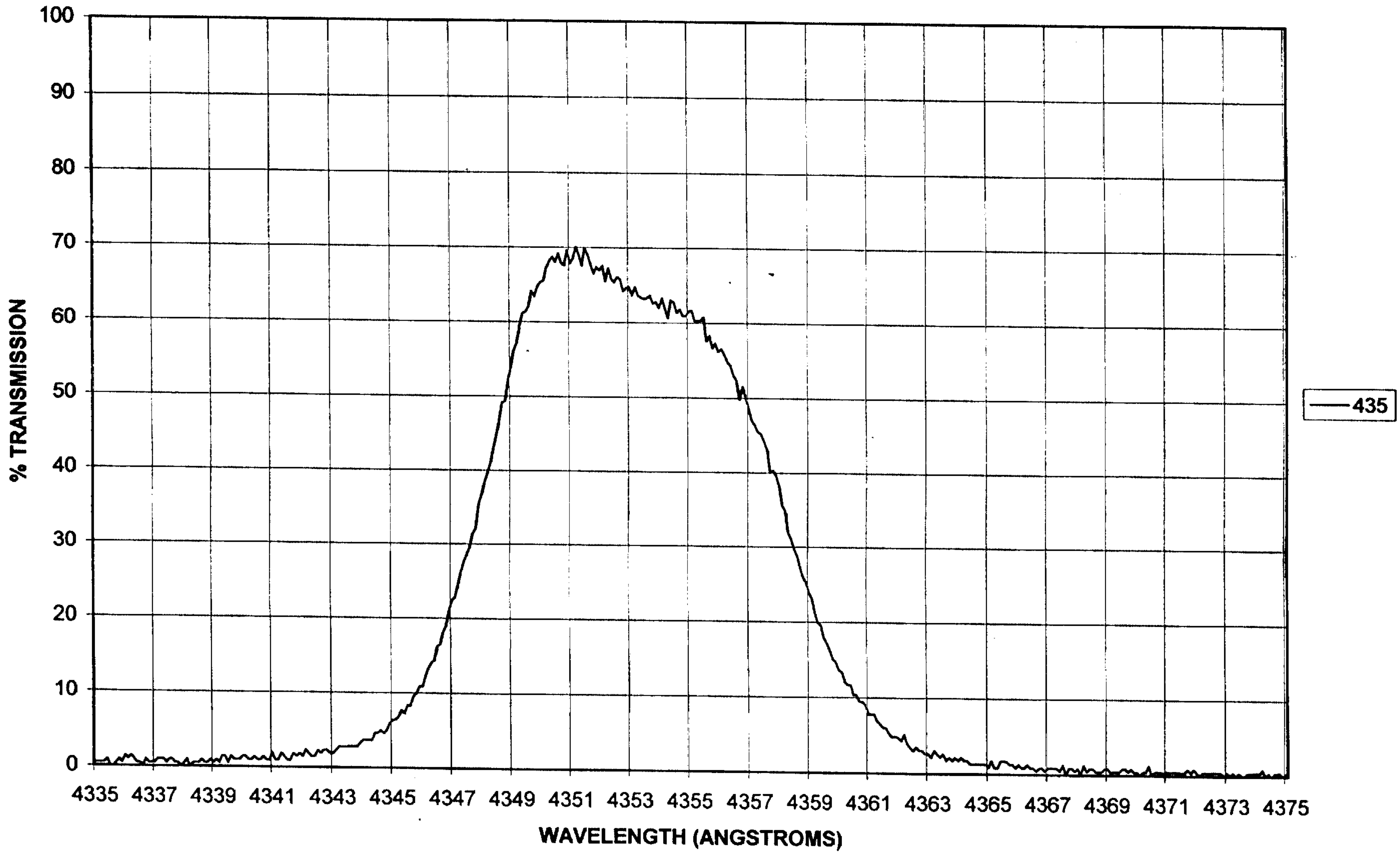

432 CHYMERA CWL = 432.77 NM/BW = 1.04 NM
% TRANSMISSION
100
90
80
70
60
50
40
30
20
10
0
4308
4310
4312
4314
4316
4318
4320
4322
4324
4326
4328
4330
4332
4334
4336
4338
4340
4342
4344
4346
4348
WAVELENGTH(ANGSTROMS)
432.8

4699:432-BLK

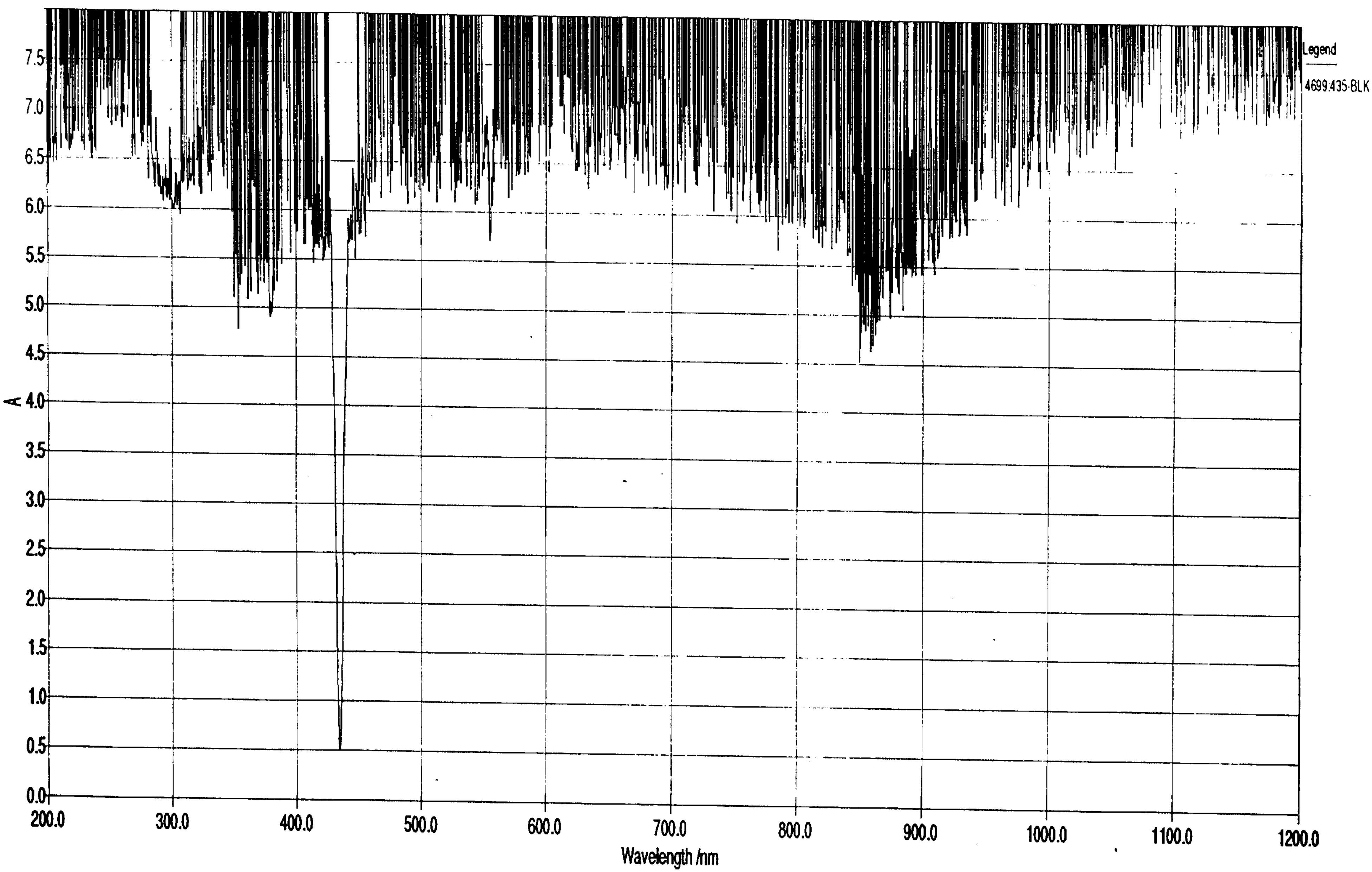


Legend
4699:432-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

CHYMERA 435 - CWL=435.31NM/BW=1.03NM

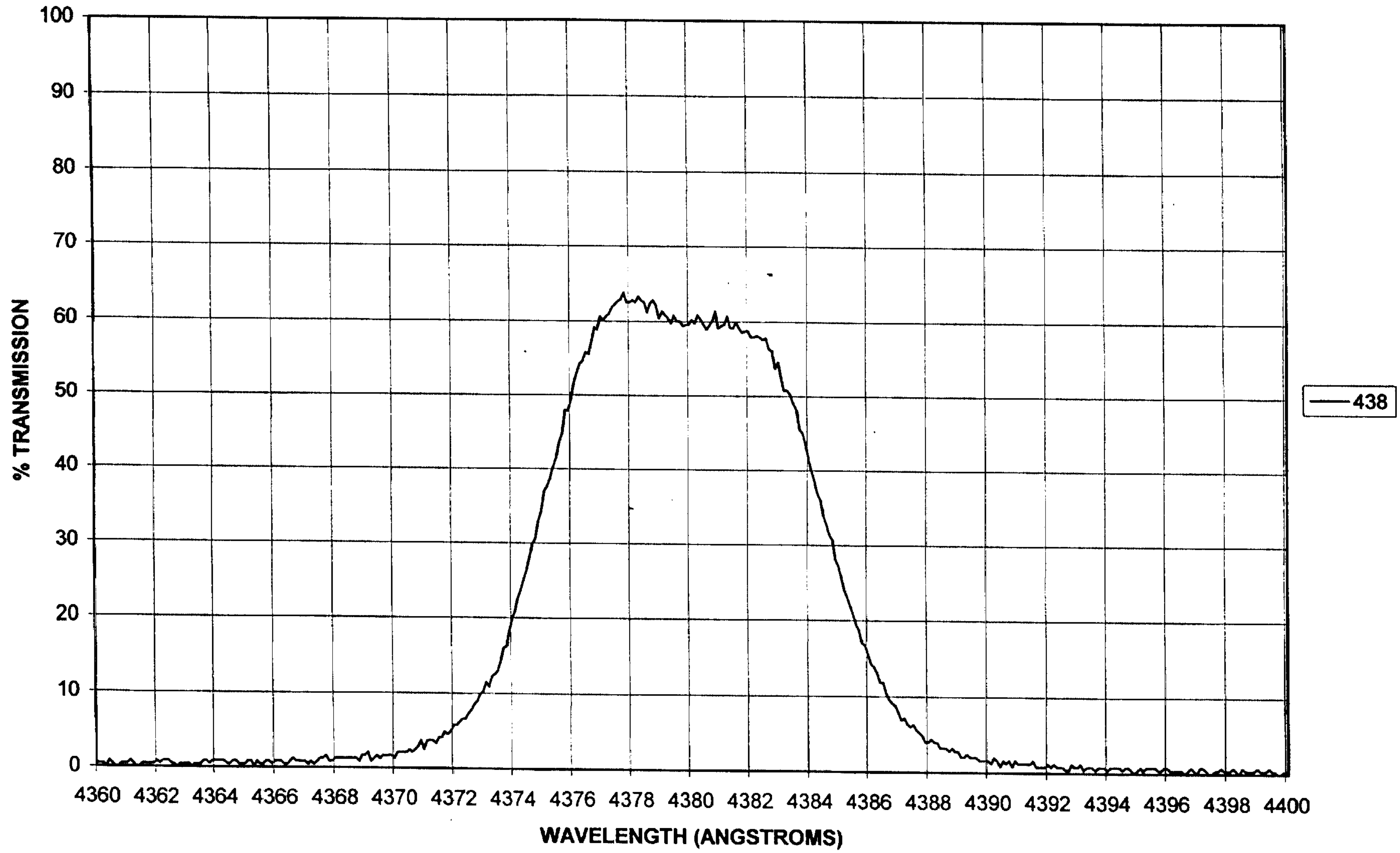


4699:435-BLK

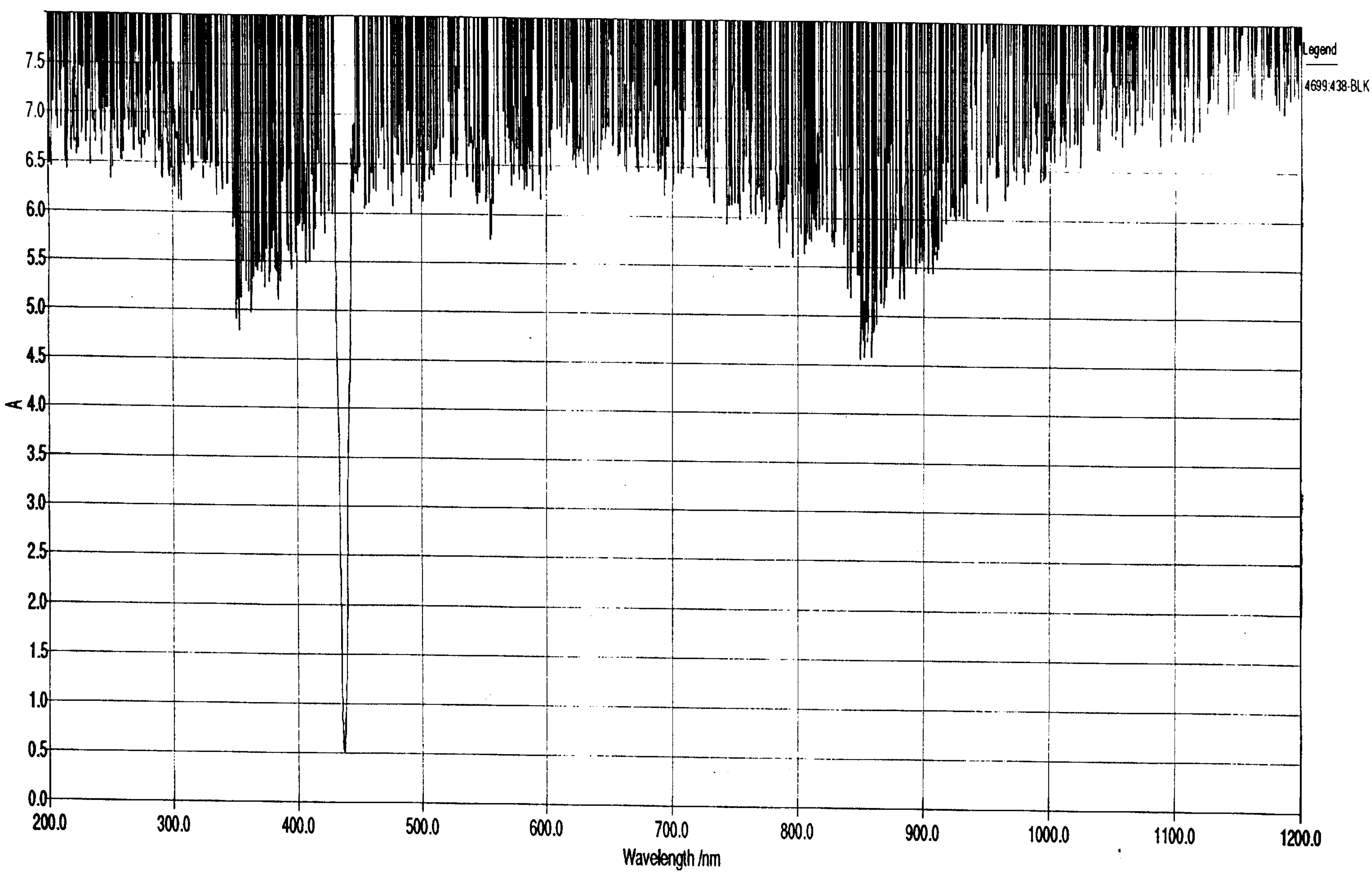


Legend
4699.435-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

CHYMERA 438 - CWL=437.98NM/BW=0.98NM

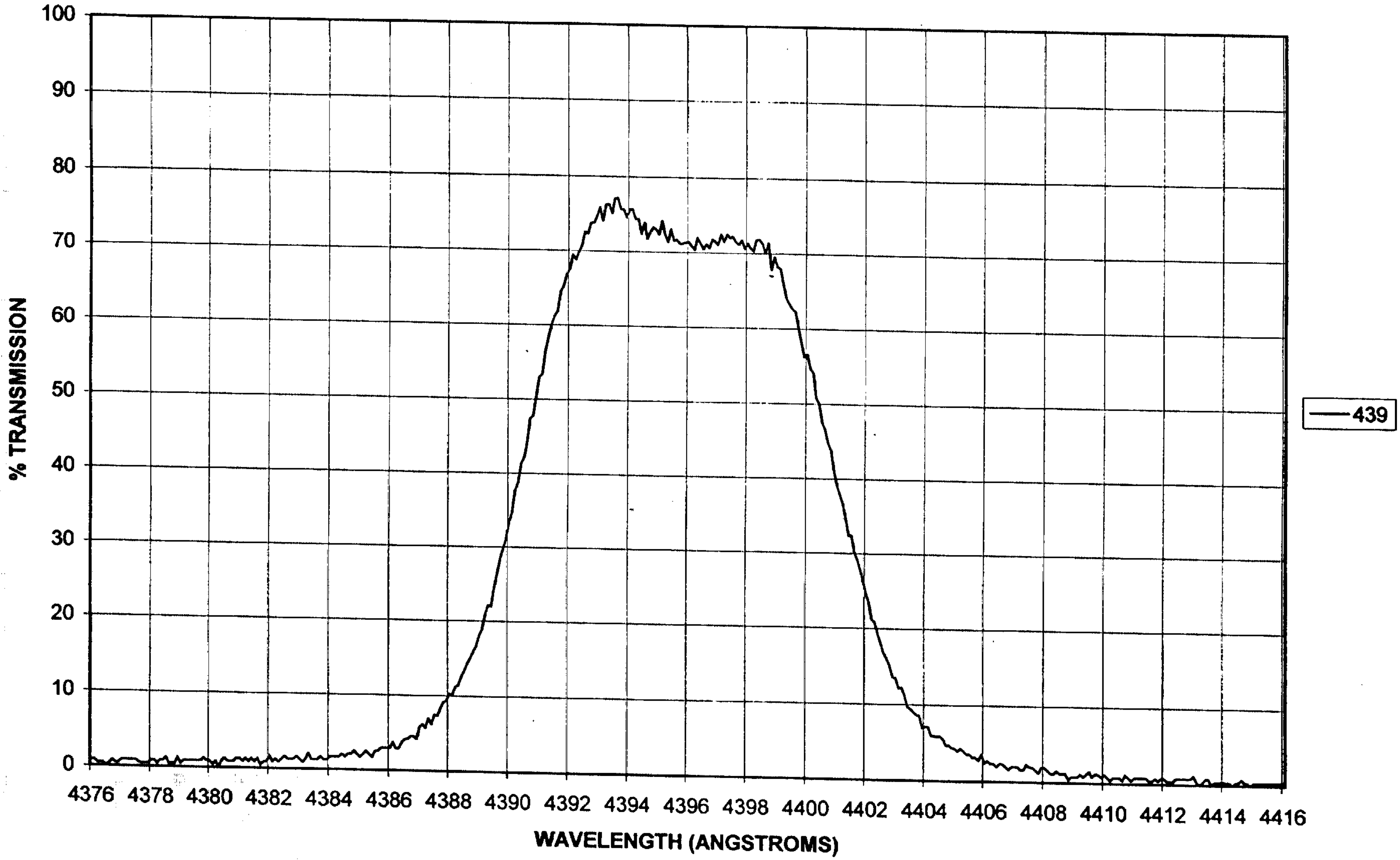


4699:438-BLK

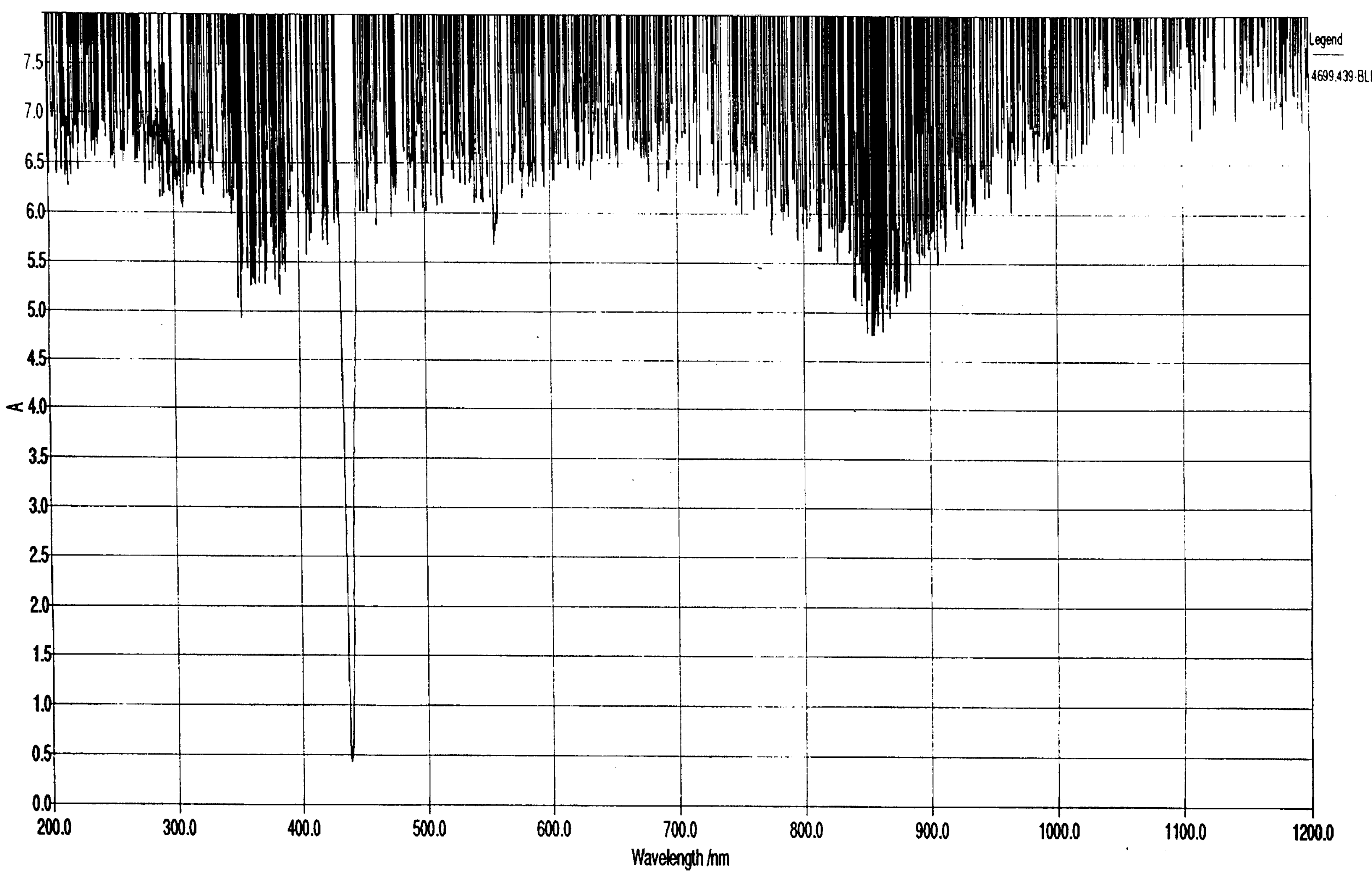


Legend
4699:438-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

CHYMERA 439 - CWL=439.57NM/BW=1.08NM



699:439-BLK


Legend
4699.439-BLK
A
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
Wavelength /nm

Appendix C – Coastal Optics Wide field telescope

- Lens prescription
- Predicted optical properties
- AR coating performance

System/Prescription Data

File : C:\ZEMAX\SAMPLES\q99137_w_filters_as_manu.ZMX
Title: f/4.86 With Filters AS Manu
Date : WED DEC 1 1999
Configuration 3 of 3

AS MANUFACTURED LENS PRESCRIPTION
WITH ACTUAL:
RADII
THICKNESSES
AIR - SPACES

LENS NOTES:

Notes...

GENERAL LENS DATA:

Surfaces	:	22
Stop	:	8
System Aperture	:	Entrance Pupil Diameter = 3.8
Glass Catalogs	:	schott I_line MISC OLD_SCHO
Ray aiming	:	Paraxial Reference, cache on
X Pupil shift	:	0
Y Pupil shift	:	0
Z Pupil shift	:	0
Apodization	:	Uniform, factor = 0.00000E+000
Eff. Focal Len.	:	18.54396 (in air)
Eff. Focal Len.	:	18.54396 (in image space)
Back Focal Len.	:	0.2582848
Total Track	:	330.55
Image Space F/#	:	4.879988
Para. Wrkng F/#	:	4.879988
Working F/#	:	4.886542
Image Space N.A.	:	0.1019257
Obj. Space N.A.	:	1.413611e-006
Stop Radius	:	5.938541
Parax. Ima. Hgt.	:	26.22363
Parax. Mag.	:	-1.379681e-005
Entr. Pup. Dia.	:	3.8
Entr. Pup. Pos.	:	75.44582
Exit Pupil Dia.	:	5362.378
Exit Pupil Pos.	:	-26168.08
Field Type	:	Object height in Millimeters
Maximum Field	:	1900702
Primary Wave	:	0.4162
Lens Units	:	Millimeters
Angular Mag.	:	0.0007086409

Fields : 5
Field Type: Object height in Millimeters

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	2.000000
2	0.000000	480000.000000	1.000000
3	0.000000	960000.000000	1.000000
4	0.000000	1344000.000000	1.000000
5	0.000000	1900702.080000	0.600000

Vignetting Factors

#	VDX	VDY	VCX	VCY
1	0.000000	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000	0.000000
3	0.000000	0.000000	0.000000	0.000000
4	0.000000	0.000000	0.000000	0.000000
5	0.000000	0.000000	0.000000	0.000000

Wavelengths : 9
Units: Microns

#	Value	Weight
1	0.413400	1.000000

2	0.416200	1.000000
3	0.426300	1.000000
4	0.429600	1.000000
5	0.431000	1.000000
6	0.432500	1.000000
7	0.435100	1.000000
8	0.437700	1.000000
9	0.439300	1.000000

SURFACE DATA SUMMARY:

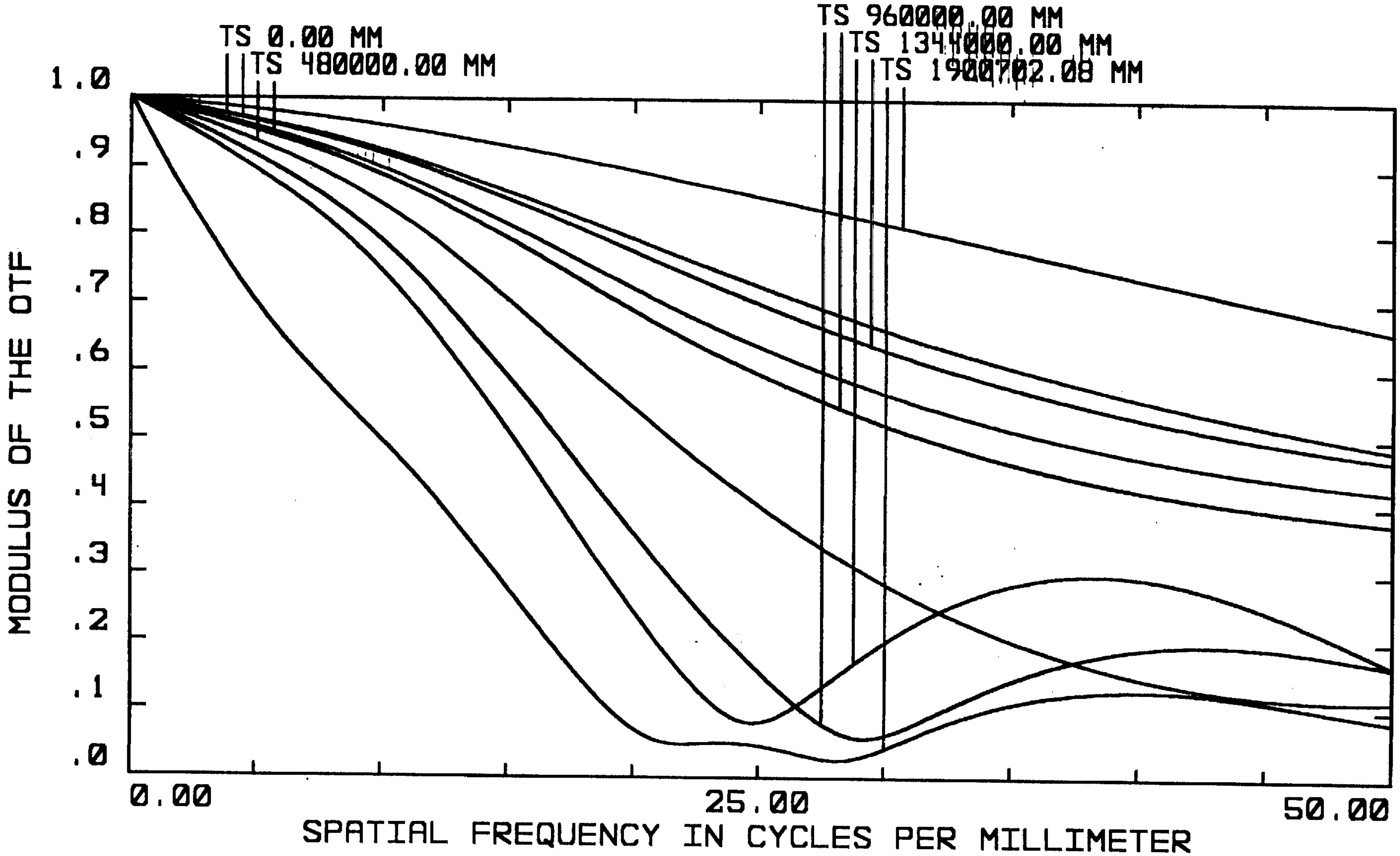
Surf	Type	Comment	Radius	Thickness	Glass	Di
OBJ	STANDARD		Infinity	1344000		3
1	STANDARD		Infinity	17.0688		
2	STANDARD	AS MANU #1	-256.205	16.077	CAF2	
3	STANDARD	AS MANU #1	37.005	62.787		
4	STANDARD	AS MANU #1	242.47	11.085	I-BAL35Y	
5	STANDARD	AS MANU #1	-67.06	0.713		
6	STANDARD	AS MANU #1	-120.82	26.929	~~CAF2~~	
7	STANDARD	AS MANU #1	31.22	46.63468		
STO	STANDARD		Infinity	12		11
9	STANDARD	AS MANU #1	111.04	30.306	CAF2	
10	STANDARD	AS MANU #1	-59.51	16.214		
11	STANDARD	AS MANU #1	-120.35	3.496	I-PBL6Y	
12	STANDARD	AS MANU #1	41.82	1.96		
13	STANDARD	AS MANU #1	50.5	9.823	CAF2	
14	STANDARD	AS MANU #1	-64.83	0.532		
15	STANDARD	AS MANU #2	45.08	12.69236	CAF2	
16	STANDARD	AS MANU #2	-166.28	54.90516		
17	STANDARD	FILTER	Infinity	1.6	B270	
18	STANDARD	FILTER	Infinity	3	~~SK11~~	
19	STANDARD	FILTER	Infinity	1.6	B270	
20	STANDARD	.005" AIRSPACE	Infinity	0.127		
21	STANDARD	CCD WINDOW	Infinity	1	SILICA	
IMA	STANDARD		Infinity			

SURFACE DATA DETAIL:

Surface OBJ : STANDARD
Surface 1 : STANDARD
Surface 2 : STANDARD
Comment : AS MANU #1
Coating : HEAR1
Surface 3 : STANDARD
Comment : AS MANU #1
Coating : HEAR1
Surface 4 : STANDARD
Comment : AS MANU #1
Coating : HEAR1
Surface 5 : STANDARD
Comment : AS MANU #1
Coating : HEAR1
Surface 6 : STANDARD
Comment : AS MANU #1
Coating : HEAR1
Surface 7 : STANDARD
Comment : AS MANU #1
Coating : HEAR1
Surface STO : STANDARD
Surface 9 : STANDARD
Comment : AS MANU #1
Coating : HEAR1
Surface 10 : STANDARD
Comment : AS MANU #1
Coating : HEAR1
Surface 11 : STANDARD
Comment : AS MANU #1

```
 Coating         : HEAR1
Surface  12      : STANDARD
 Comment         : AS MANU #1
 Coating         : HEAR1
Surface  13      : STANDARD
 Comment         : AS MANU #1
 Coating         : HEAR1
Surface  14      : STANDARD
 Comment         : AS MANU #1
 Coating         : HEAR1
Surface  15      : STANDARD
 Comment         : AS MANU #2
 Coating         : HEAR1
Surface  16      : STANDARD
 Comment         : AS MANU #2
 Coating         : HEAR1
Surface  17      : STANDARD
 Comment         : FILTER
 Coating         : HEAR1
Surface  18      : STANDARD
 Comment         : FILTER
Surface  19      : STANDARD
 Comment         : FILTER
Surface  20      : STANDARD
 Comment         : .005" AIRSPACE
Surface  21      : STANDARD
 Comment         : CCD WINDOW
Surface IMA      : STANDARD

MULTI-CONFIGURATION DATA:

 Configuration    1:
 Wavelength   1 :         0.3107
 Wavelength   2 :          0.312
 Wavelength   3 :         0.3131
 Wavelength   4 :         0.3174
 Wavelength   5 :         0.3222
 Wavelength   6 :         0.3292
 Wavelength   7 :         0.3399
 Wavelength   8 :         0.3399
 Wavelength   9 :         0.3399
 Glass       17 :           UBK7
 Glass       18 :           UBK7
 Glass       19 :           UBK7
 Thickness   17 :            1.1
 Thickness   18 :              4
 Thickness   19 :            1.1

 Configuration    2:
 Wavelength   1 :         0.3879
 Wavelength   2 :         0.3879
 Wavelength   3 :         0.3879
 Wavelength   4 :         0.3879
 Wavelength   5 :         0.3933
 Wavelength   6 :         0.3933
 Wavelength   7 :         0.3933
 Wavelength   8 :         0.3933
 Wavelength   9 :         0.3933
 Glass       17 :            BK1
 Glass       18 :           SK11
 Glass       19 :           B270
 Thickness   17 :              2
 Thickness   18 :            2.7
 Thickness   19 :            1.5

Configuration    3:
Wavelength   1 :          0.4134
```

Wavelength	2 :	0.4162
Wavelength	3 :	0.4263
Wavelength	4 :	0.4296
Wavelength	5 :	0.431
Wavelength	6 :	0.4325
Wavelength	7 :	0.4351
Wavelength	8 :	0.4377
Wavelength	9 :	0.4393
Glass	17 :	B270
Glass	18 :	SK11
Glass	19 :	B270
Thickness	17 :	1.6
Thickness	18 :	3
Thickness	19 :	1.6

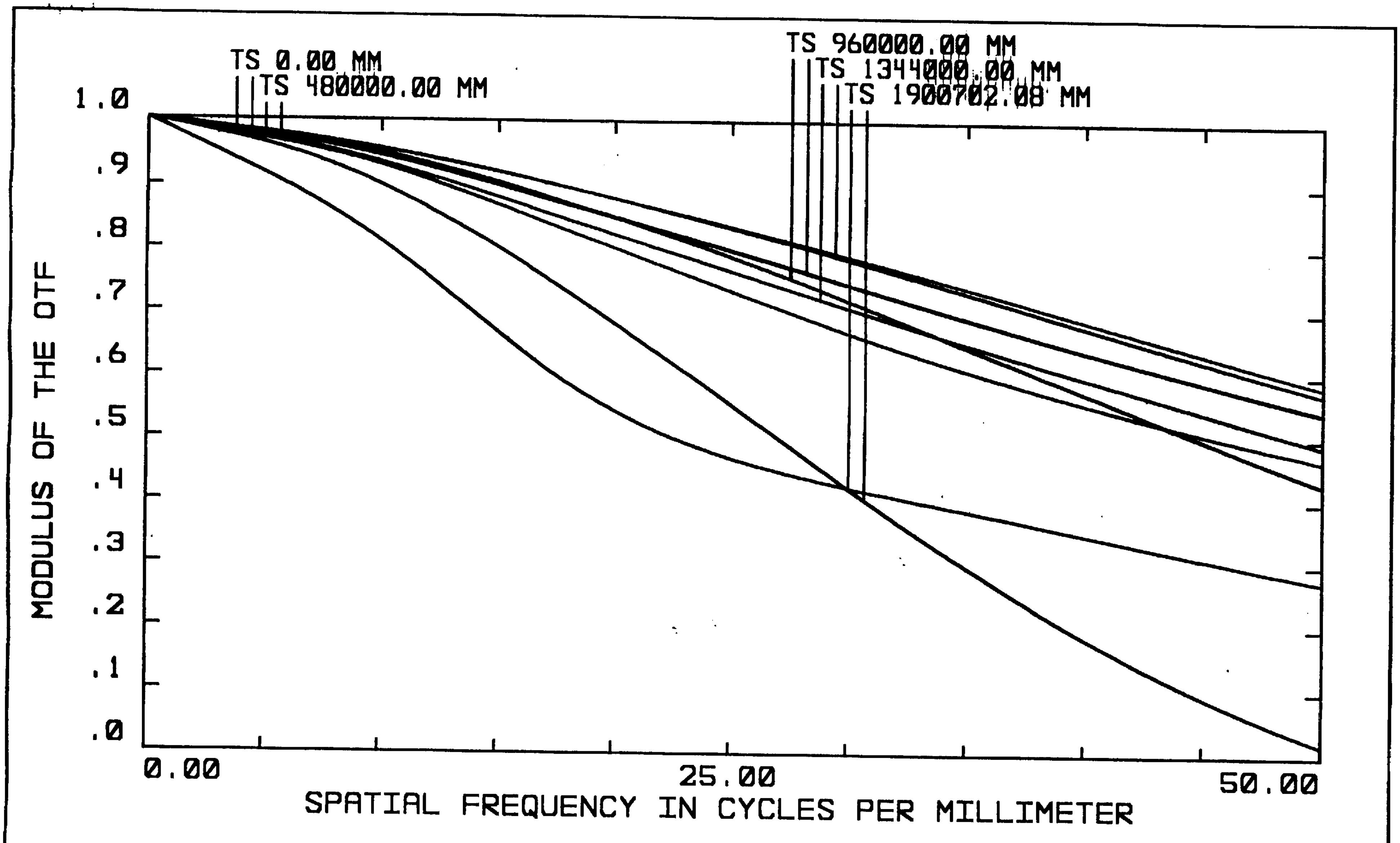


POLYCHROMATIC DIFFRACTION MODULATION TRANSFER FUNCTION

F/4.86 WITH FILTERS AS MANU
WED DEC 1 1999
DATA FOR 0.3107 TO 0.3399 MICRONS.

COASTAL OPTICAL SYSTEMS
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407

561.881.7400
CONFIGURATION 1 OF 3



POLYCHROMATIC DIFFRACTION MODULATION TRANSFER FUNCTION

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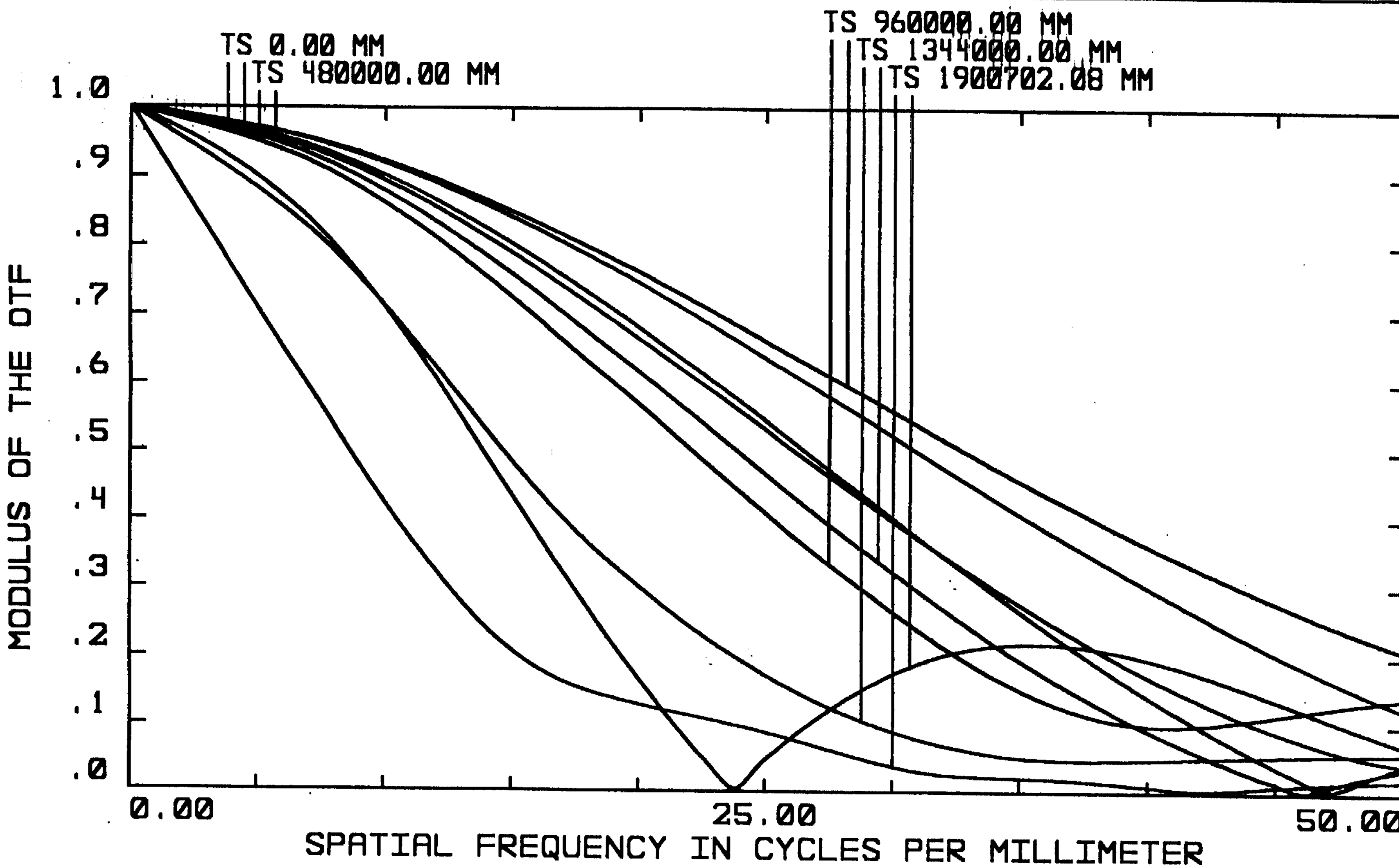
WED DEC 1 1999
DATA FOR 0.3879 TO 0.3933 MICRONS.

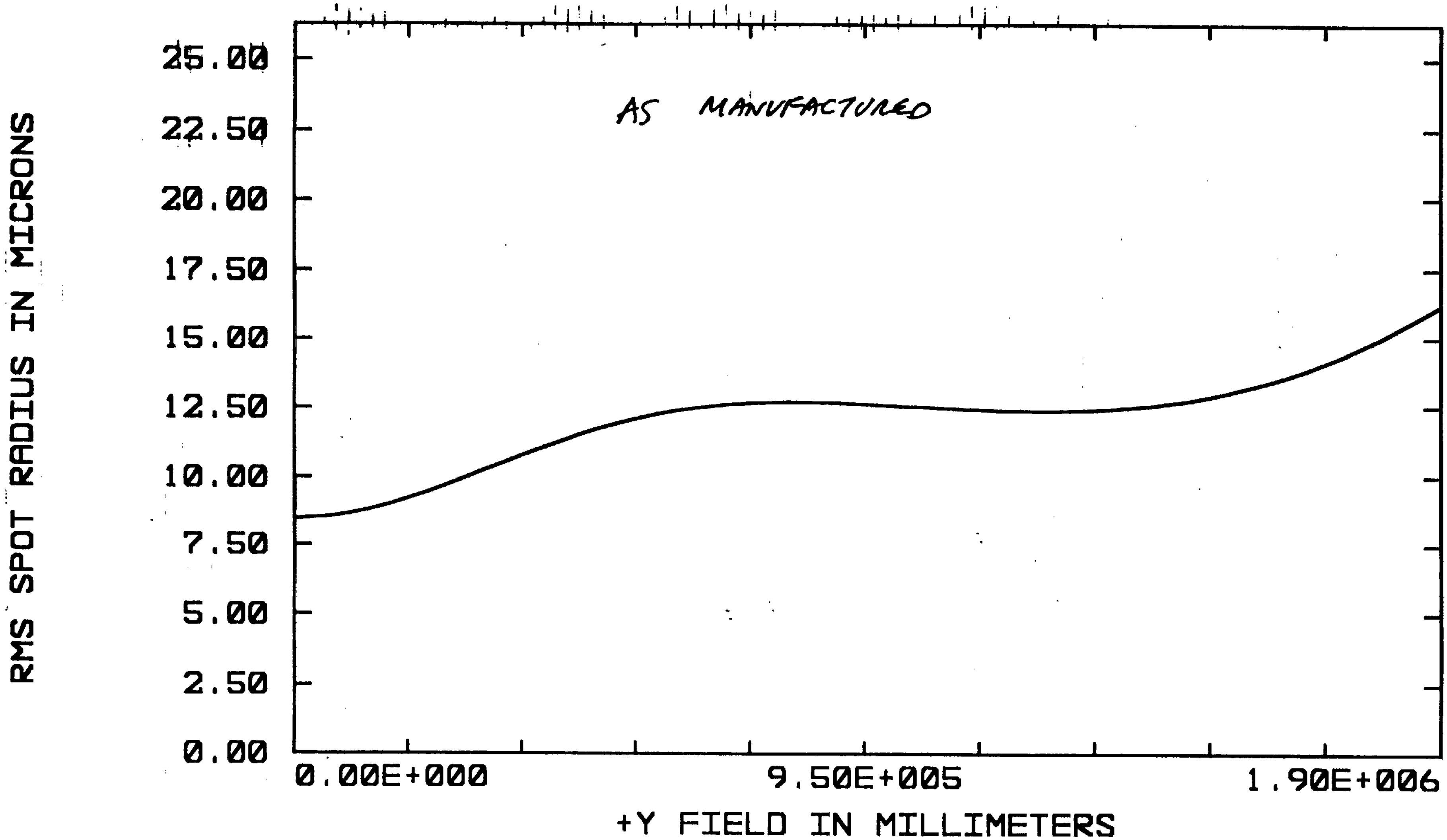
COASTAL OPTICAL SYSTEMS
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407
561.881.7400
CONFIGURATION 2 OF 3



POLYCHROMATIC DIFFRACTION MODULATION TRANSFER FUNCTION

F/4.86 WITH FILTERS AS MANU
WED DEC 1 1999
DATA FOR 0.4134 TO 0.4393 MICRONS.

COASTAL OPTICAL SYSTEMS
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407
561.881.7400
CONFIGURATION 3 OF 3

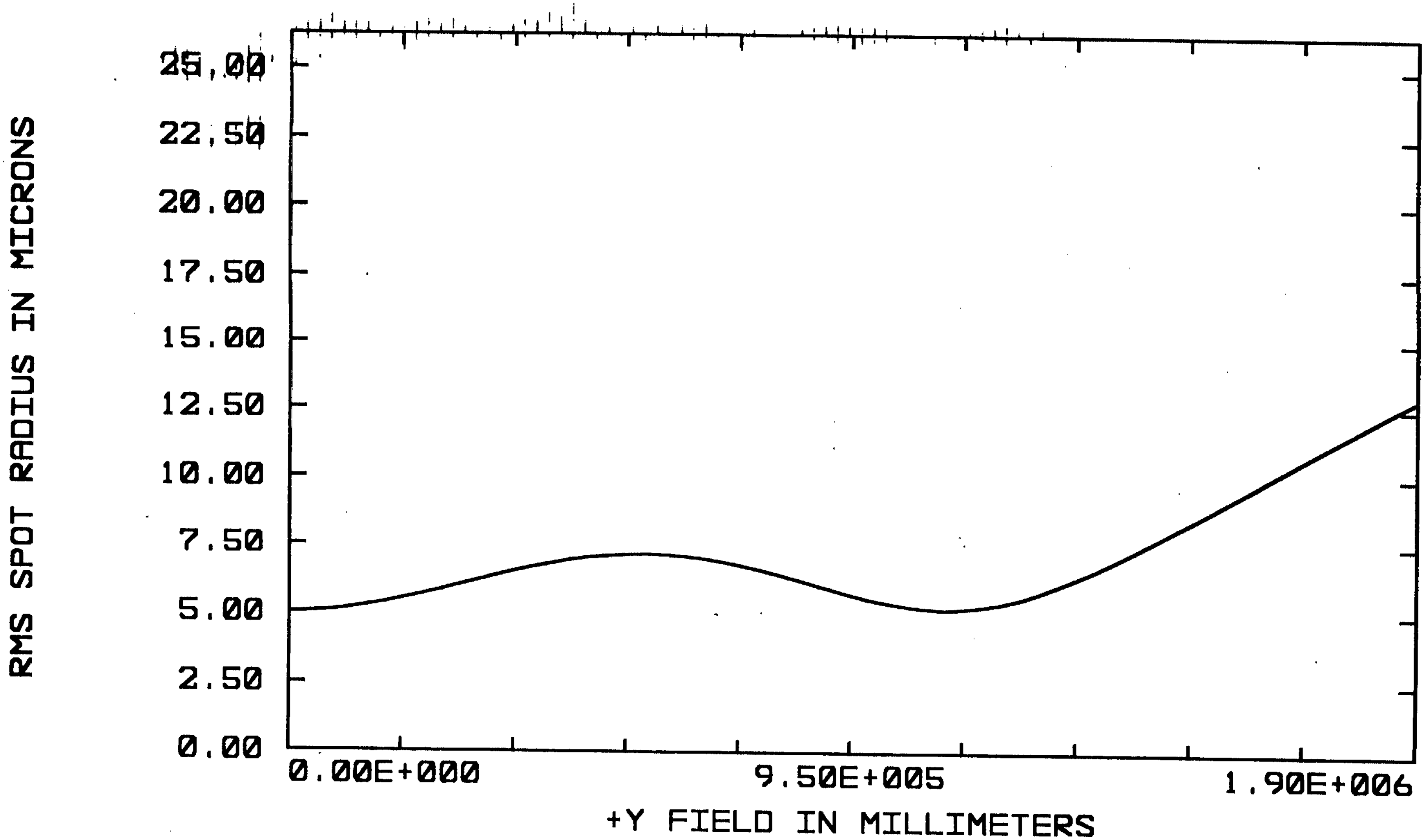


RMS SPOT RADIUS VS FIELD

F/4.86 WITH FILTERS AS MANU
WED DEC 1 1999
POLY

REFERENCE: CENTROID

COASTAL OPTICAL SYSTEMS
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407
561.881.7400
CONFIGURATION 1 OF 3

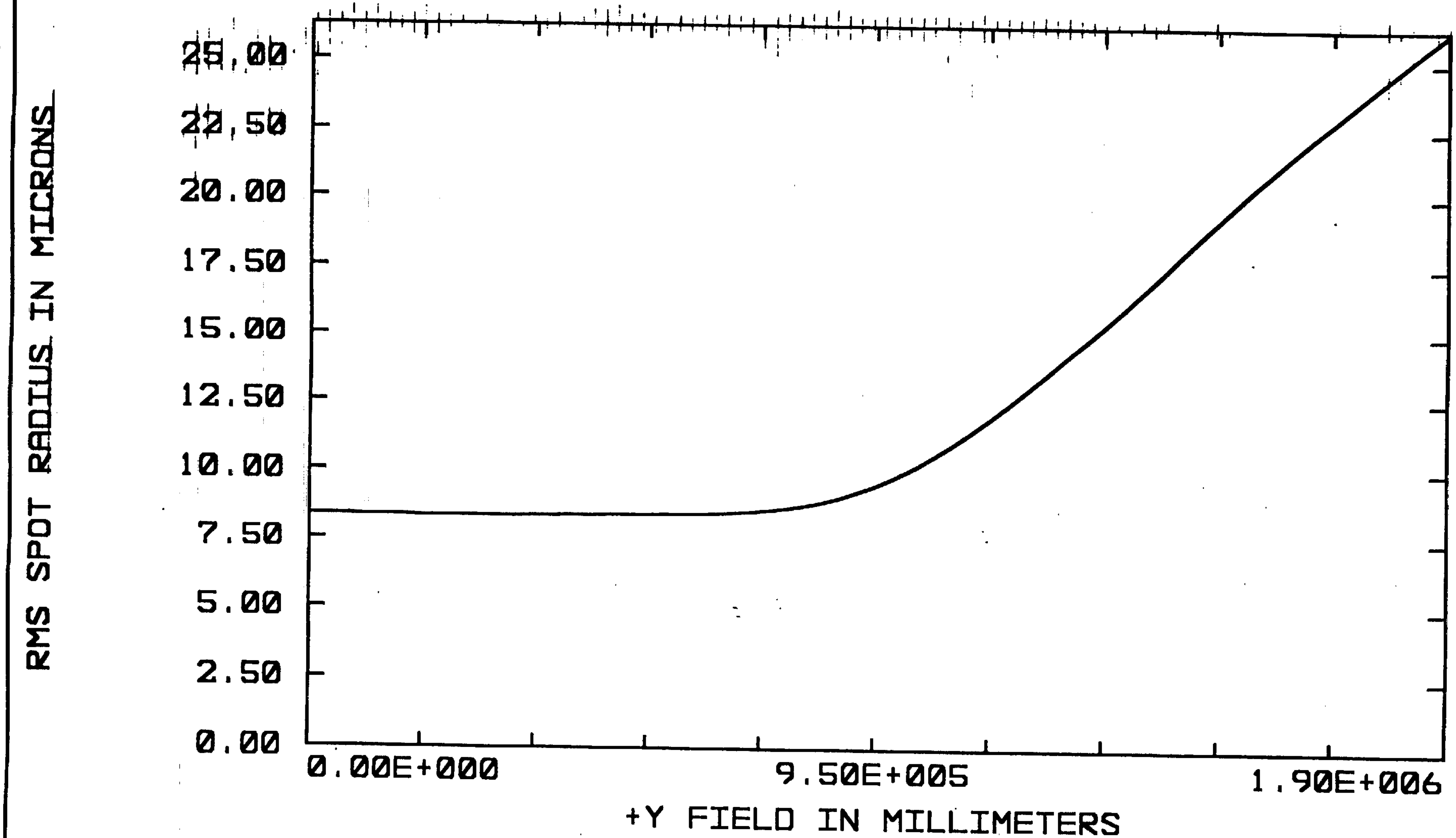


RMS SPOT RADIUS VS FIELD

F/4.86 WITH FILTERS AS MANU
WED DEC 1 1999
POLY

REFERENCE: CENTROID

COASTAL OPTICAL SYSTEMS
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407
561.881.7400
CONFIGURATION 2 OF 3



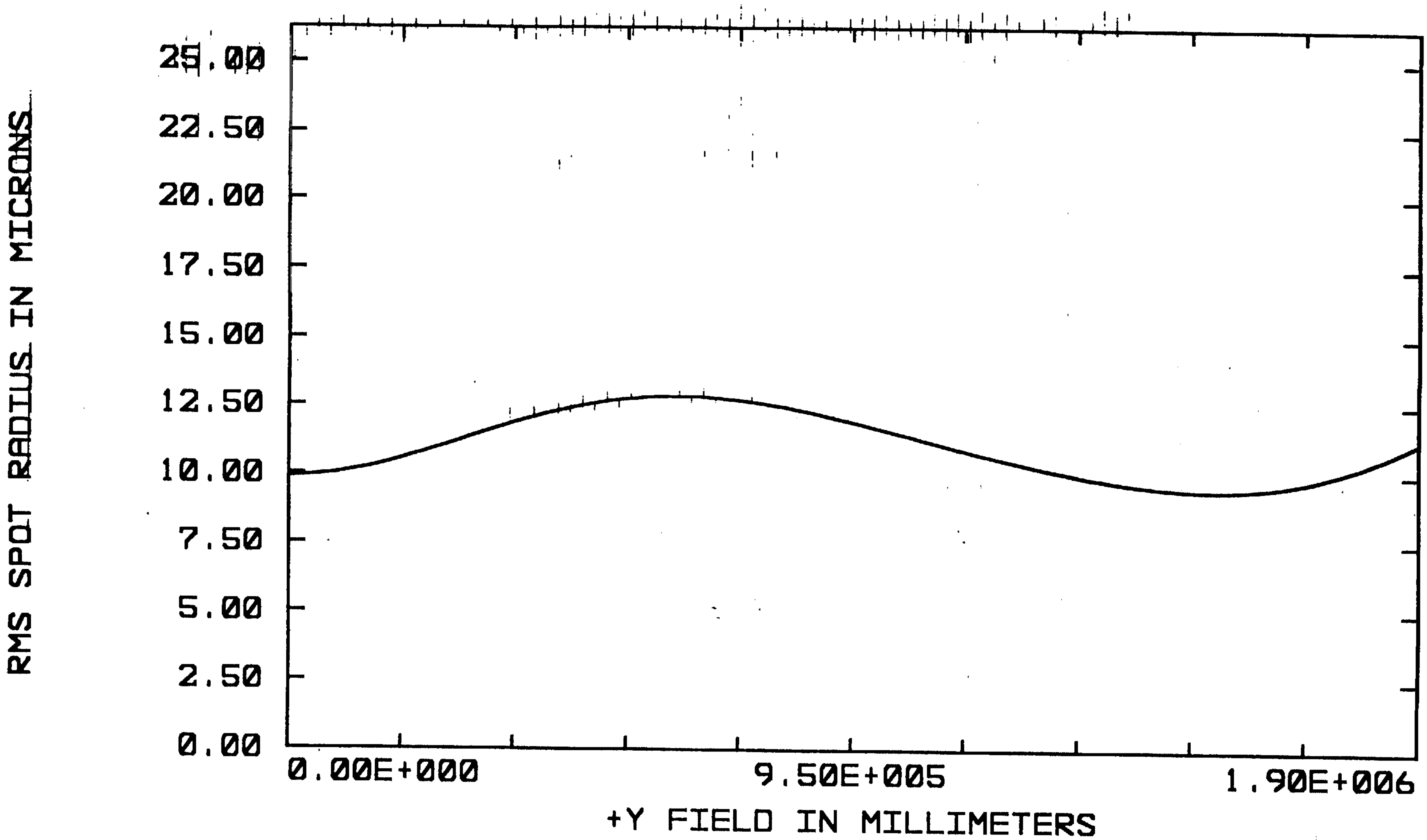
RMS SPOT RADIUS VS FIELD

F/4.86 WITH FILTERS AS MANU
WED DEC 1 1999
POLY

REFERENCE: CENTROID

COASTAL OPTICAL SYSTEMS
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407
561.881.7400
CONFIGURATION 3 OF 3

NOMINAL DESIGN



RMS SPOT RADIUS VS FIELD

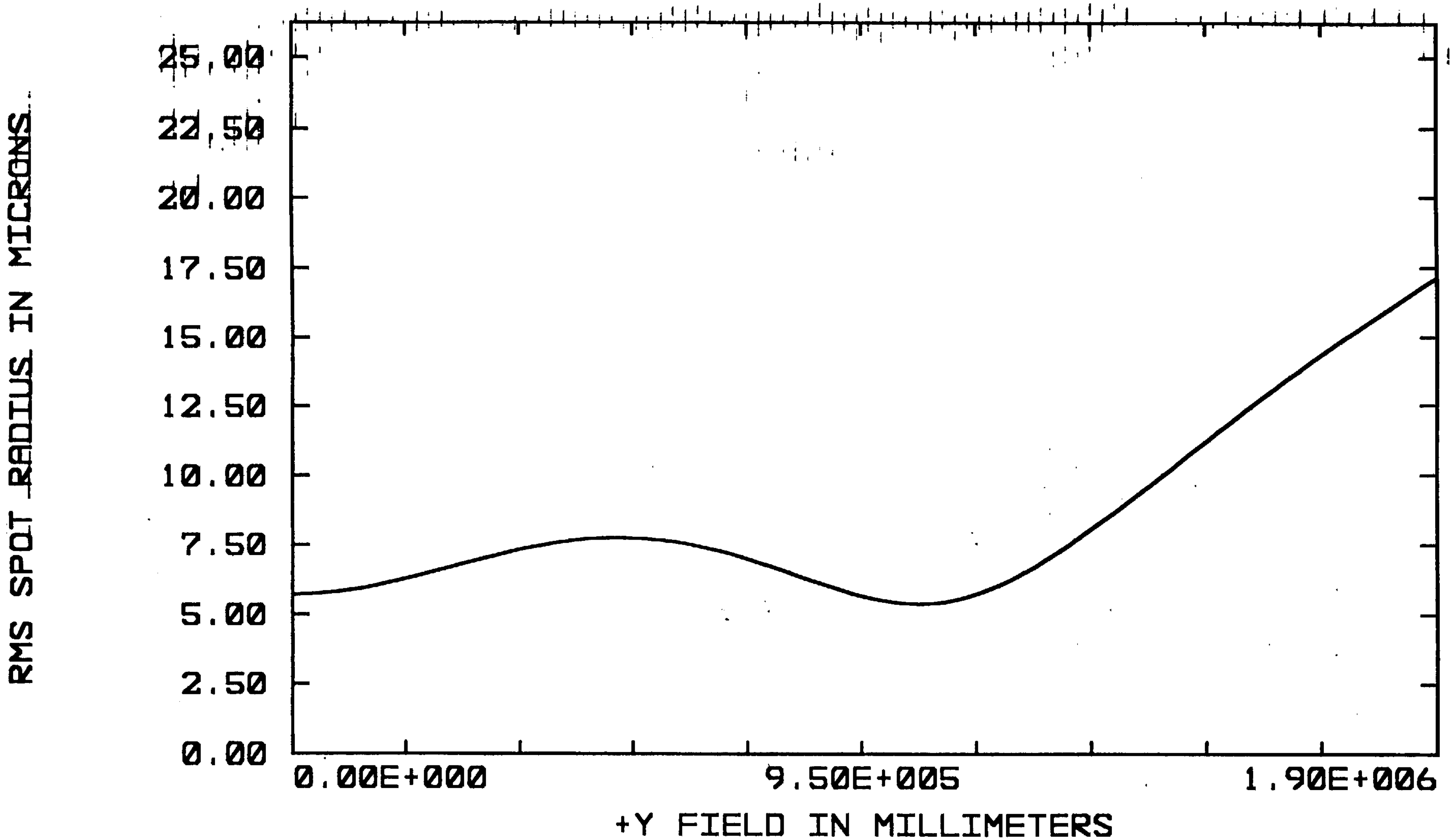
COSI 18.5 MM F/4.86 WITH FILTERS
WED DEC 1 1999
POLY

NOMINAL DESIGN
(FOR REFERENCE ONLY)

REFERENCE: CENTROID

COASTAL OPTICAL SYSTEMS
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407
561.881.7400

CONFIGURATION 1 OF 3



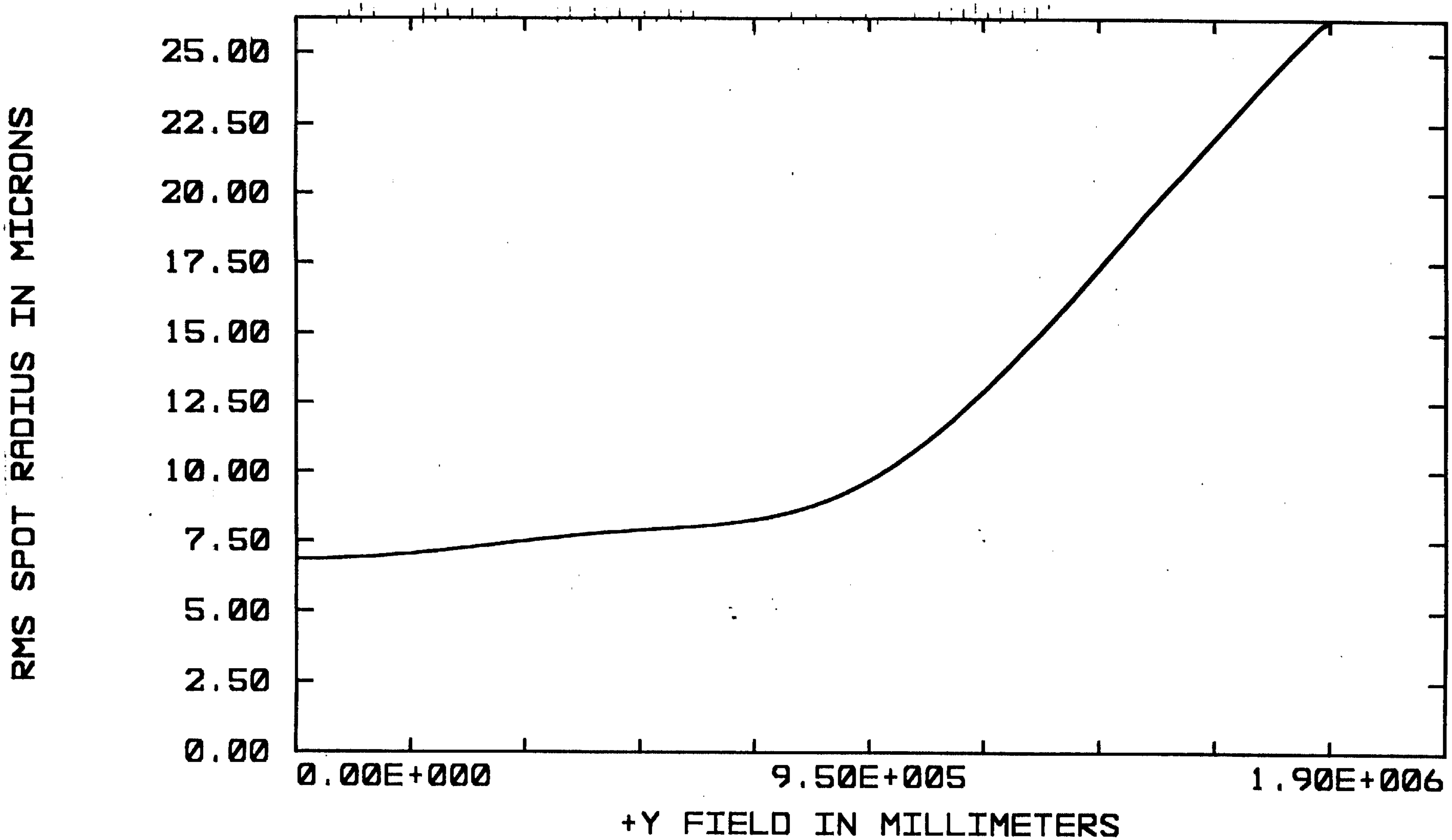
RMS SPOT RADIUS VS FIELD

COSI 18.5 MM F/4.86 WITH FILTERS
WED DEC 1 1999
POLY

NOMINAL DESIGN

REFERENCE: CENTROID

COASTAL OPTICAL SYSTEMS
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407
561.881.7400
CONFIGURATION 2 OF 3



RMS SPOT RADIUS VS FIELD

COSI 18.5 MM F/4.86 WITH FILTERS
WED DEC 1 1999
POLY

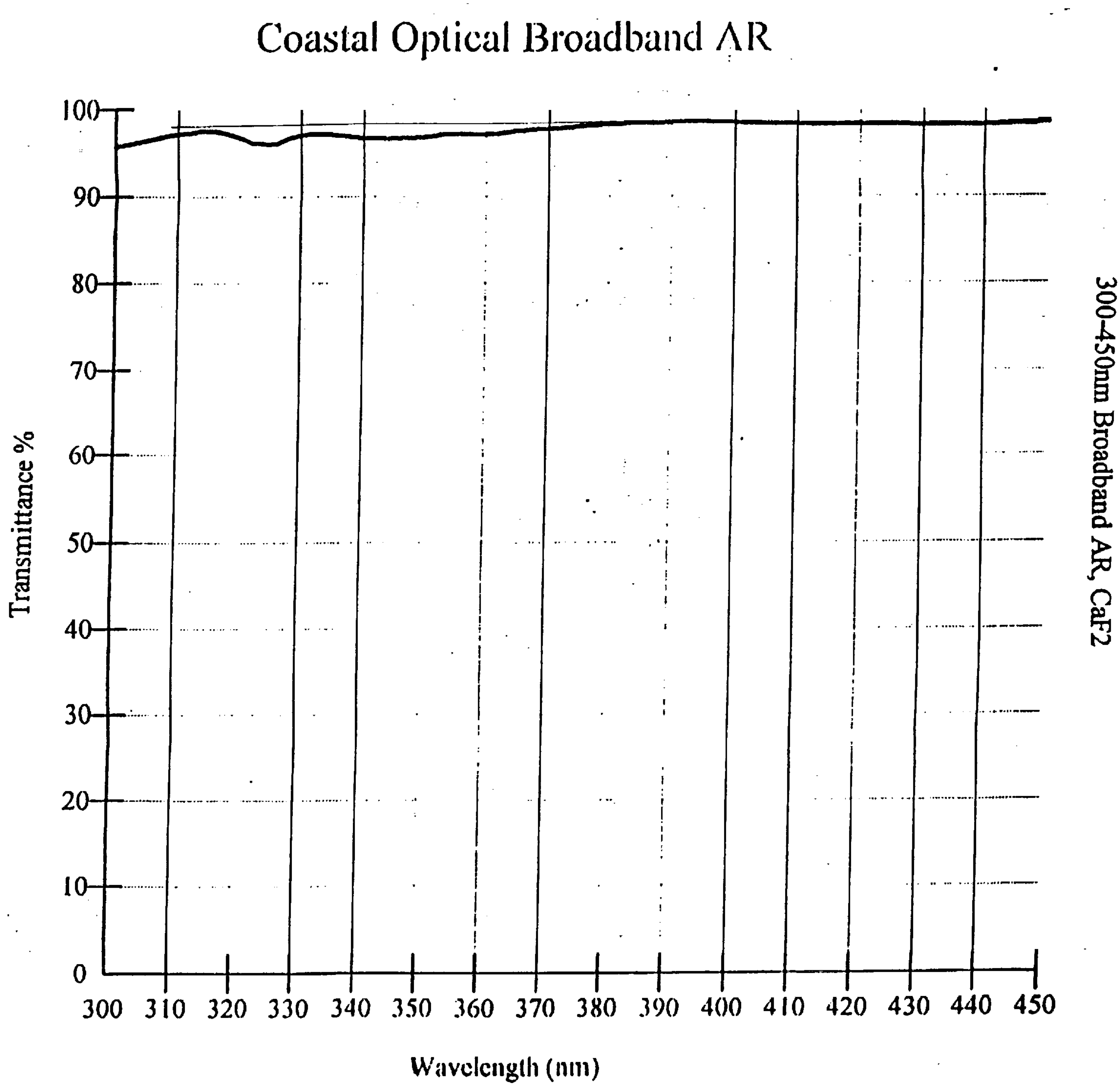
NOMINAL DESIGN

REFERENCE: CENTROID

COASTAL OPTICAL SYSTEMS
4480 SOUTH TIFFANY DRIVE
WEST PALM BEACH, FL 33407
561.881.7400
CONFIGURATION 3 OF 3

ACTON RESEARCH CORPORATION
CAMS-507 Vacuum Spectrophotometer

Filename: AR_X2_01
300-450nm AR on CaF2
Peak: 98.7 at 450.00 nm
Date: 11/23/99 10:59:12 AM



REPORT DOCUMENTATION PAGE

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1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
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13. ABSTRACT *(Maximum 200 words)*

CHyMERA is an Instrument Incubator concept to design, build, and test an instrument that will reduce size, mass, and cost and increase science potential and flexibility for future atmospheric remote sensing missions within the focus of NASA's Earth Science Enterprise (ESE). The primary effort of the development plan will be on high spatial resolution ozone, NO2, SO2, aerosol, and cloud measurements, but it is hoped that the techniques developed will prove useful for other measurements as well. The core design will involve a high performance, wide field-of-view (FOV) front end telescope which will illuminate a filter/focal plane array (FFPA) package. The use of a non-dispersive optical configuration will reduce size, mass and complexity. The wide FOV optics will permit short duration global coverage (1-2 days) without the need for a scanner.

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