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System Requirements Review for the High-Resolution Ozone Imager (HIROIG)

15 September 1993

Prepared by

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Space and Environment Technology Center
Technology Operations

Prepared for

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Development Group

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JOHN R. EDWARDS, Project Officer
SMC/CEV

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INTRODUCTION

D. L. MCKENZIE



HIROIG SYSTEM REQUIREMENTS REVIEW

Feb 17, 1993

David McKenzie

HIROIG

HIGH RESOLUTION OZONE IMAGER



HIROIG SYSTEM REQUIREMENTS REVIEW

Feb 17, 1993

David McKenzie

PROBLEM

- UP TO 30% OF SOLID ROCKET MOTOR EXHAUST IS CHLORINE
- LOCAL OZONE DEPLETION BY CHLORINE
- KNOWLEDGE OF OZONE DEPLETION BY SRM LAUNCHES IS REQUIRED FOR DoD TO COMPLY WITH FEDERAL ENVIRONMENTAL LAWS
- MEASUREMENT OF OZONE DEPLETION REQUIRES A UV SPECTROMETER HAVING UNPRECEDENTED SPATIAL RESOLUTION AND THE ABILITY TO MEASURE THE POLARIZATION OF BACKSCATTERED SUNLIGHT: HIROIG



HIROIG SYSTEM REQUIREMENTS REVIEW

Feb 17, 1993
David McKenzie

PLANS FOR FY 1993

- **CONSTRUCT TWO GROUND-BASED PROTOTYPE INSTRUMENTS**
 - **PRISM SPECTROMETER**
 - **GRATING SPECTROMETER**
- **PREPARE FOR PRELIMINARY DESIGN REVIEW IN OCTOBER 1993**



HIROIG SYSTEM REQUIREMENTS REVIEW

Feb 17, 1993
David McKenzie

PERSONNEL

SCIENCE TEAM

DAVID MCKENZIE - FLIGHT INSTRUMENT DEVELOPMENT
JIM HECHT - INSTRUMENT DEVELOPMENT
MARTY ROSS - THEORY
GEORGE ROSSANO - INSTRUMENT DEVELOPMENT
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JIM SKINNER - MECHANICAL DESIGN
NORM KATZ - DETECTOR ELECTRONICS
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JON OSBORN - ELECTRONICS DESIGN
KIRK CRAWFORD - SOFTWARE
PATTY LIU - DETECTOR ELECTRONICS (USC INTERN)



HIROIG SYSTEM REQUIREMENTS REVIEW

Feb 17, 1993

David McKenzie

AGENDA

INTRODUCTION

McKENZIE (5)

SCIENCE OVERVIEW

ROSS (10)

INSTRUMENT REQUIREMENTS

HECHT (15)

OPTICAL DESIGN

GUTIERREZ (10)/ROSSANO (5)

MECHANICAL DESIGN

SIVJEE (5)

DATA PROCESSING UNIT

MABRY (5)

MANAGEMENT AND SCHEDULES

STEIN (5)



SCIENCE OVERVIEW

M. N. ROSS

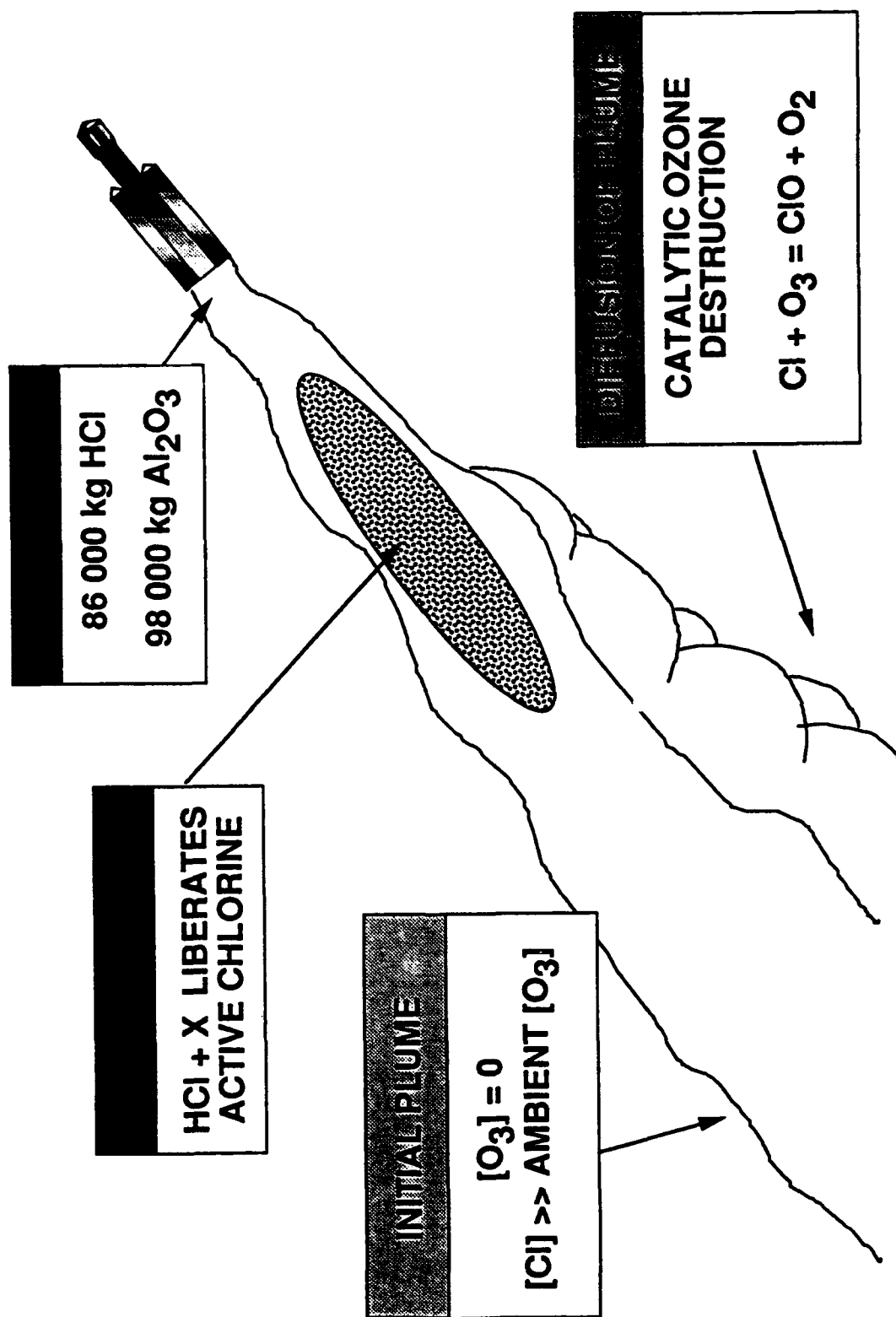
HIROIG SCIENCE

- **Rockets as sources of stratospheric ozone depleting chemicals**
- **Characteristics of rocket plume ozone depletion**
- **Backscatter method of ozone measurement**
- **Measurement requirements for plume ozone loss detection**

LAUNCH VEHICLES AS STRATOSPHERIC POLLUTERS

- motor types:
 - solids (ammonium perchlorate)
 - liquids (hypergolic, cryogenic)
- exhaust products are not well known
 - gases (CO_2 , CO , OH , H_2O , NO , Cl)
 - solids (Al_2O_3 or cryogen aerosols of uncertain size distribution)
- vehicles
 - shuttle (1)
 - titan IV (.6)
 - energia (2.2)
 - ariane V (.4)

SOLID MOTOR EXHAUST CHEMISTRY

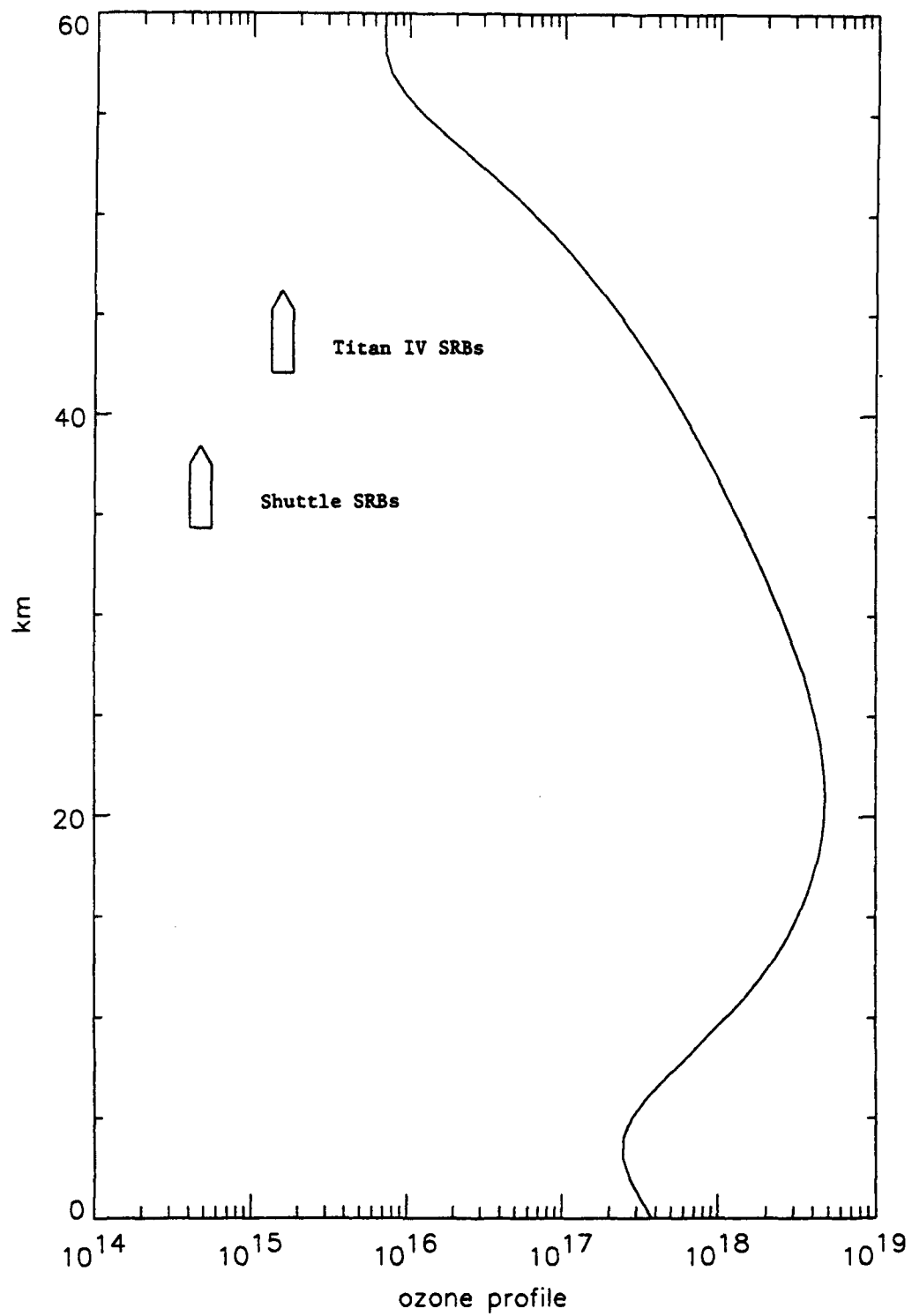


THREE STAGES IN PLUME DYNAMICS

1. initial plume: 0 to about 15 min after launch
 - optically thick
 - cools to ambient
 - from industry plume flowfield models
 - $[O_3] = 0$
2. intermediate plume: 15 min to about 6(?) hours after launch
 - diffusion and advection of plume into stratosphere
 - optically thin but aerosols contribute to radiative environment
 - best chance to observe ozone loss
3. terminal plume: 6(?) hours +
 - loss of plume structure
 - diffusion of ozone rich ambient air into plume

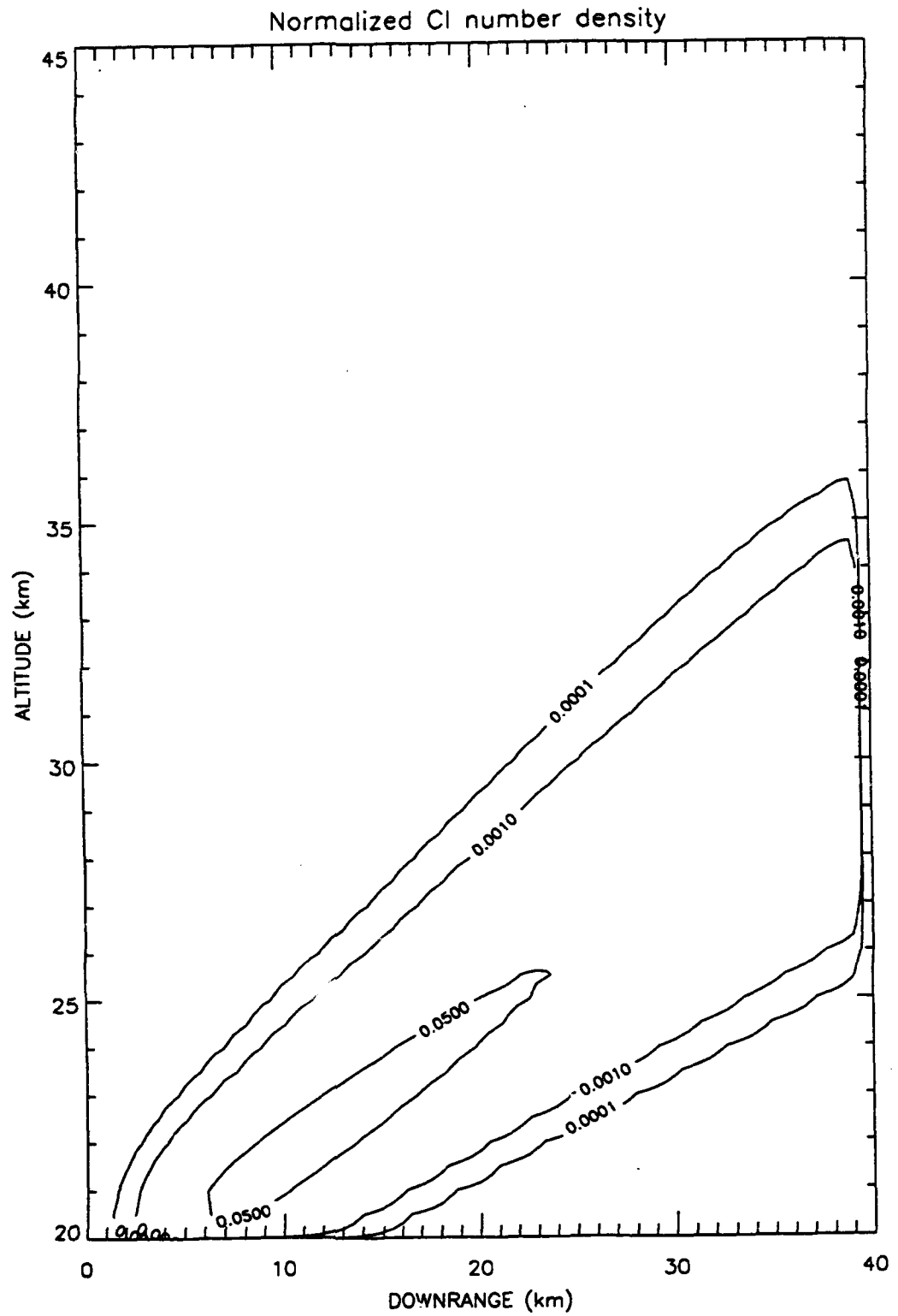
FIRST ORDER PLUME CHEMISTRY

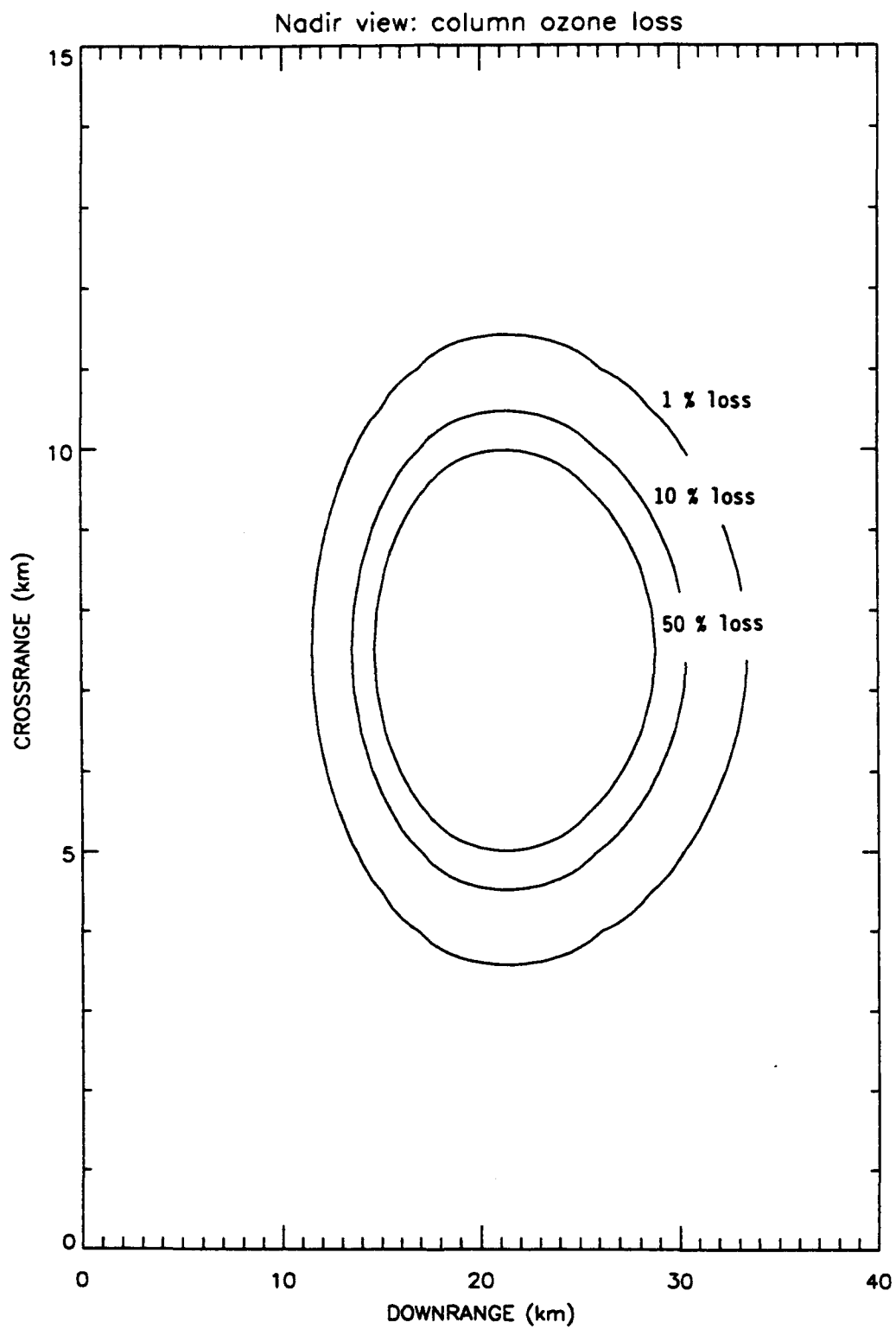
- Cl is very abundant in the initial plume
 - $2-5 \times 10^{16} \text{ m}^{-3}$
 - $\text{Cl} + \text{O}_3 \rightarrow \text{ClO} + \text{O}_2$ is main reaction in the first hours
- as mixing proceeds in the plume O_3 essentially is replaced by ClO
- detailed atmospheric chemistry models verify this view
- 3-D model needed

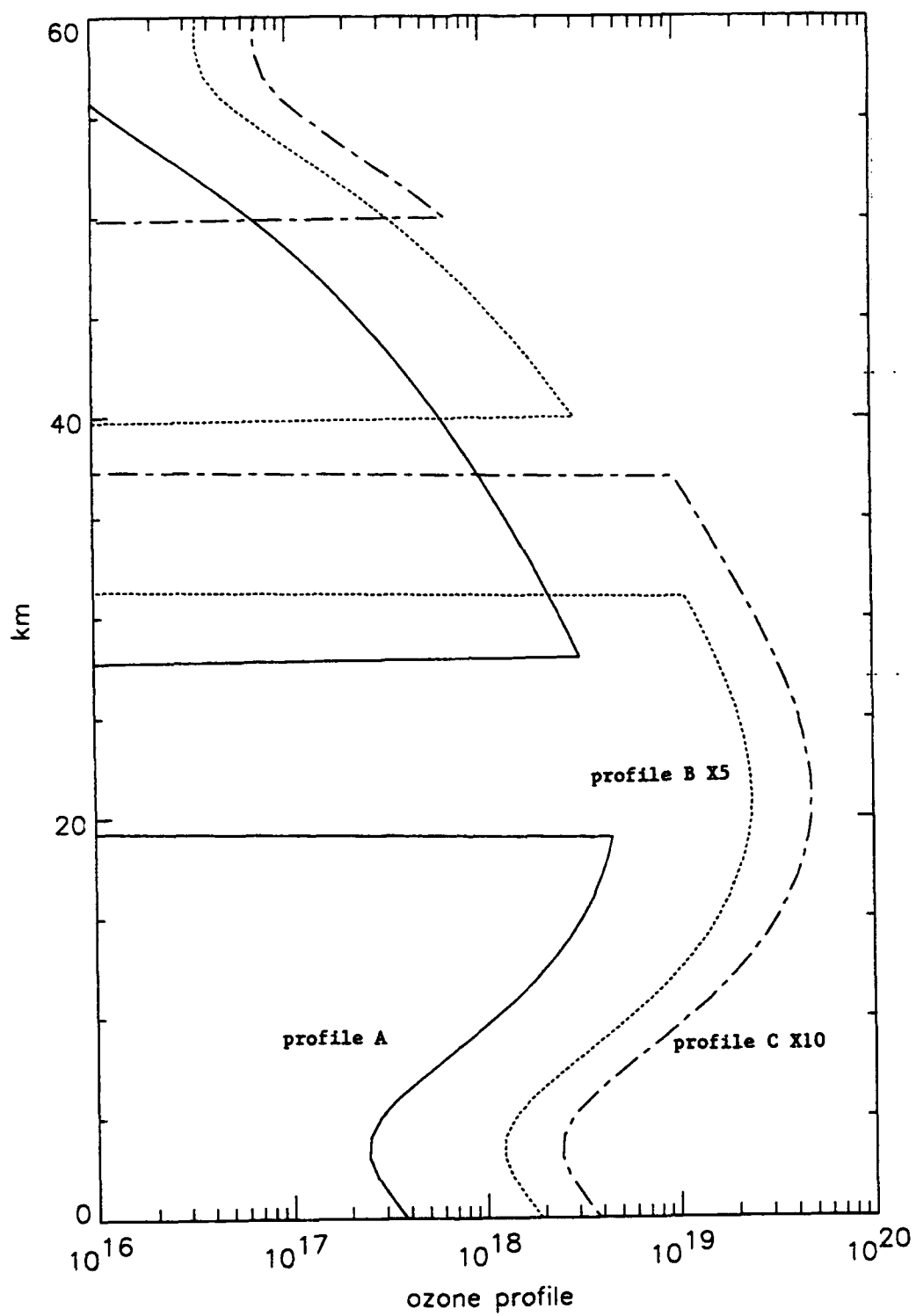


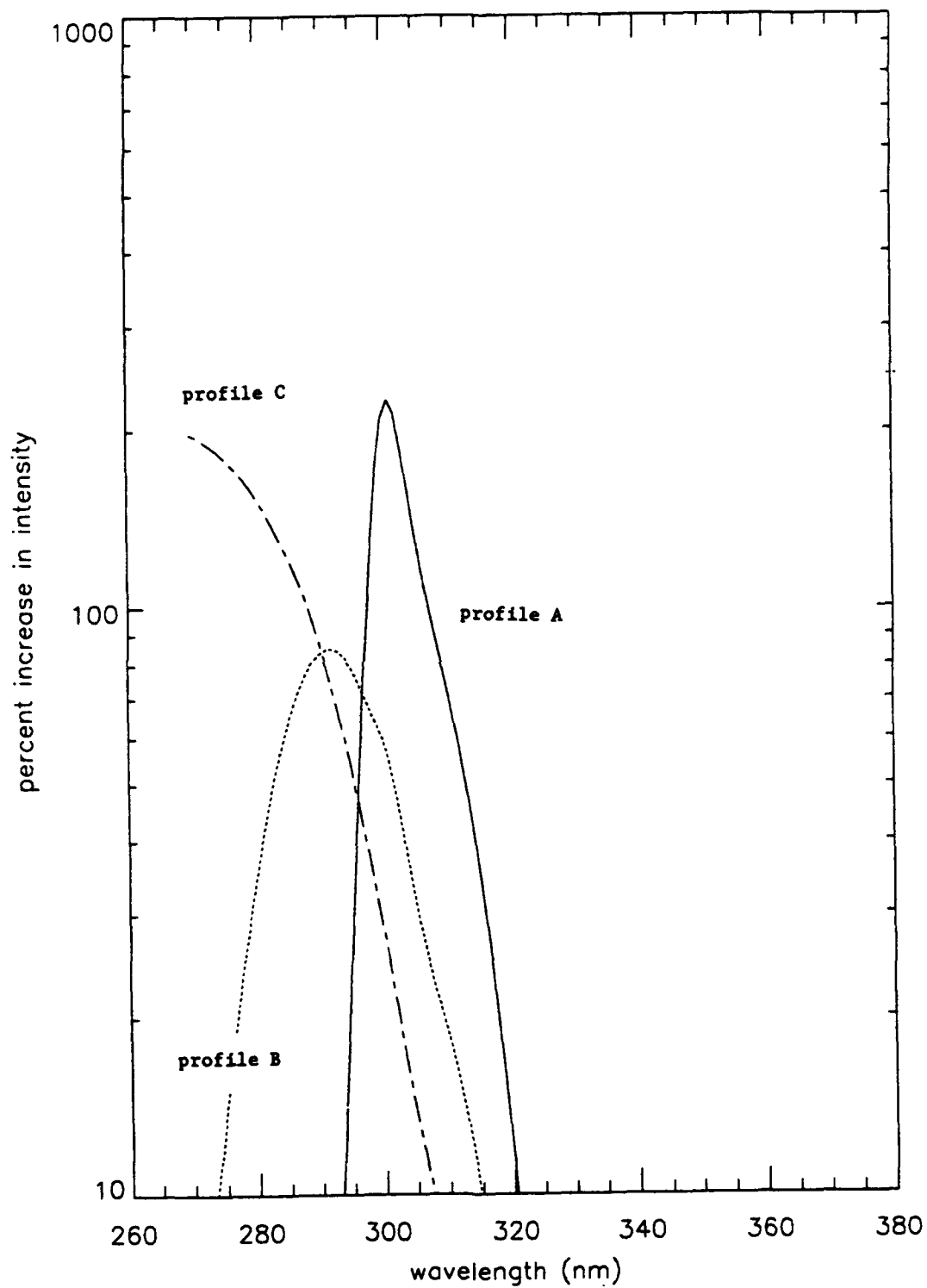
PRELIMINARY PLUME MODEL

- initial goal is for instrument design purposes
 - resolution and sensitivity
 - data rates
- 3-D diffusion/advection model
 - 'bare bones' chemistry: Cl and O₃ only
 - isothermal
- characteristics:
 - 20 - 45 km altitude
 - linear increase of D_h with altitude (50 - 100 m²/s)
 - $D_h/D_v = 2$
 - trajectory parallel to wind (10 - 20 m/s)



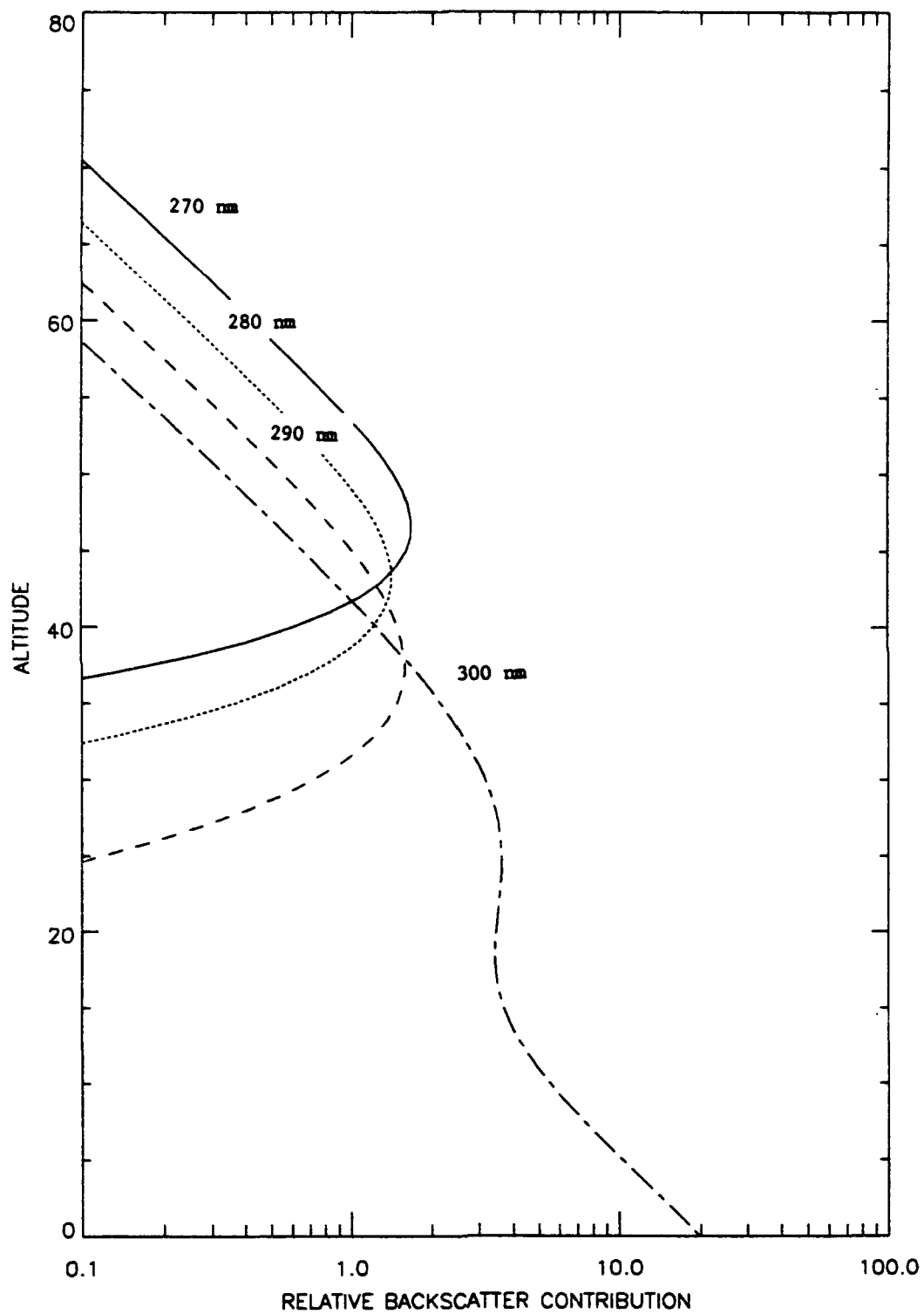






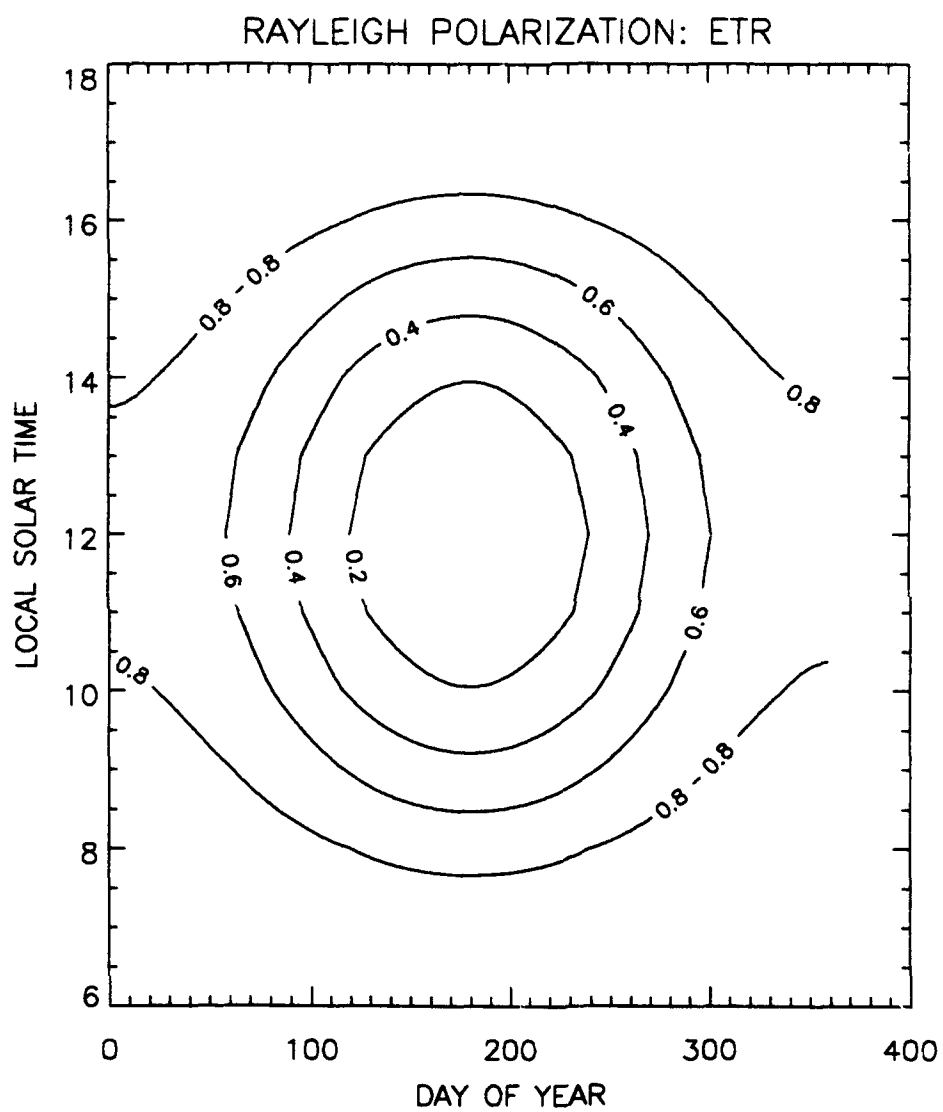
OZONE MEASUREMENT METHOD

- **SOLAR ULTRAVIOLET BACKSCATTER**
 - **EXPLOITS WAVELENGTH DEPENDENCE OF OZONE ABSORPTION**
 - **MID UV CONTRIBUTION FUNCTIONS COVER STRATOSPHERE FROM 20 TO 50 KM**
 - **VERTICAL RESOLUTION OF 5 TO 10 KM**
 - **LONG HERITAGE (SBUV, TOMS, DE)**



COMPLICATIONS TO BACKSCATTER TECHNIQUE

- **Aerosols:**
 - exhaust contains .1 to 10 micron particles
 - will contribute significantly to radiative environment
 - *solution*: measure the polarization of the backscatter-molecular scattering is strongly polarized;
aerosol scattering is not



COMPLICATIONS TO BACKSCATTER TECHNIQUE

(continued)

- In the plume region ozone is replaced by ClO:
 - ClO absorption cross section is similar to ozone
 - *solution*: use spectral features in ClO cross section to recover ClO profile
- Low resolution (i.e. TOMS) uses 1-D inversion: high resolution will require development of 3-D inversion

HIROIG DESIGN

• MEASUREMENT GOALS LEAD TO DESIGN SPECS

- RESOLVE PLUME	2 KM PIXELS
- OZONE PROFILE	270 -370 NM AT 2 NM
- AEROSOL COMPONENT	POLARIZATION STATE
- OBSERVE > 50% OF EVENTS	SUN SYNCHRONOUS ORBIT CROSS TRACK POINTING



INSTRUMENT REQUIREMENTS

J. H. HECHT

INTRODUCTION

The High Resolution Ozone Imager (HIROIG) is a new space-based spectrograph:

- Ozone density
 - 800 km orbit
 - backscattered solar light 270-370 nm
- Change in Ozone after a rocket launch
 - spatial resolution (2 X 2 km)
 - NASA TOMS - 50 X 50 km pixel
- Polarization
 - aerosols

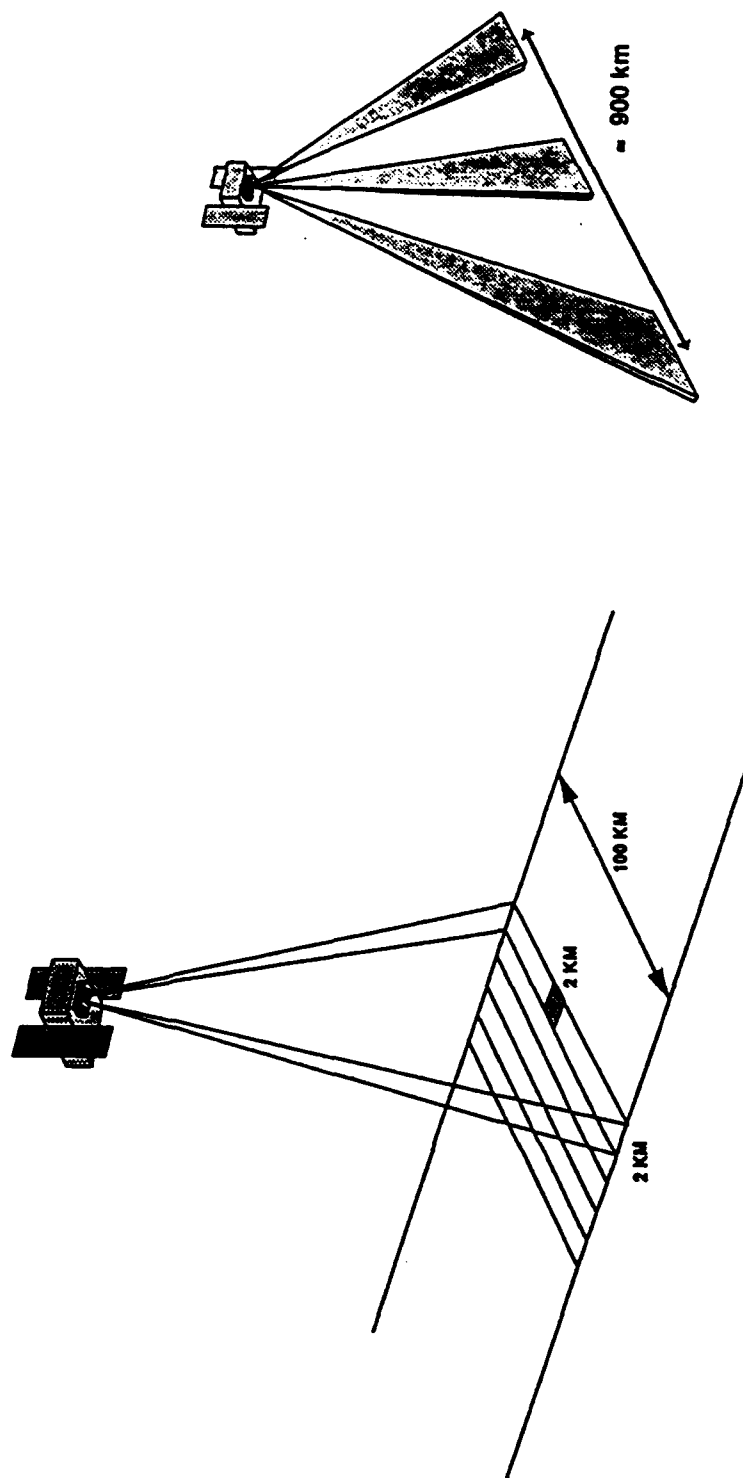
OVERVIEW

- HIROIG design - four spectrographs - CCD Detectors
 - one dimension is spectral - 270 to 370 nm
 - other dimension is spatial
- Typical CCD image
 - exposed for 1/7 second
 - 90 X 130 pixels (100 X 100 microns)
 - Focal plane of 9 X 13 mm
 - 100 X 100 micron pixel
 - 1 nm spectral (270-370 nm)
 - 1 km X 1 km spatial
 - effective resolution of 2 nm and 2 X 2 km
 - 100 km by 1 km strips
- second spatial dimension via motion of the spacecraft

Feb. 17, 1993
Jim Hecht

HIROIG

PUSH-BROOM OPERATION



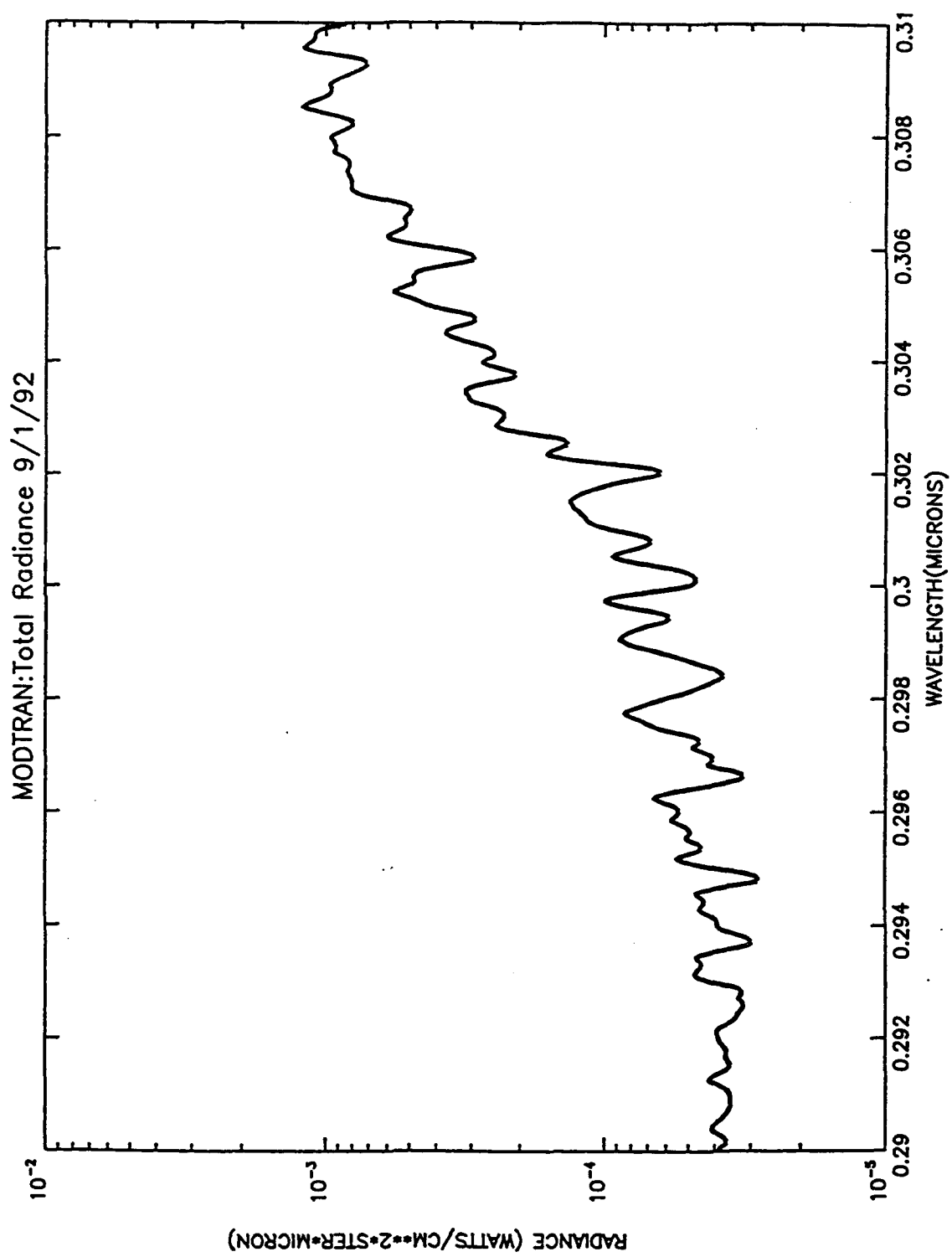
- gimbal mounted
 - 30 degrees from nadir pointing
- The four spectrographs are each sensitive to light polarized at different angles
 - three angles - uniquely determine polarization
 - 0, 45, 90
 - fourth 0 or 135
 - increase the signal to noise in backscattered signal
 - correct for radiation induced degradation of the CCD

- HIROIG Design Difficulties
 - large amount solar light - eliminated prior to entrance slit
 - steepness of the solar curve - 270 to 370 nm (1000:1)
- Solutions
 - Pre-filtering - suppress unwanted solar photons outside the bandpass from entering the instrument
 - The optical design of the spectrograph is such that internal scattering is minimized.

DESIGN CRITERIA

- CCD will be used as a detector
 - large signals - 10^7 counts over focal plane
 - large number of pixels - 10^4
- spectral resolution - 2 nm from 270 to 350 nm
 - goal - 1 nm through this wavelength range
- spatial resolution - 2 X 2 km at 800 km
 - goal 1 X 1 km
- cross track field of view 100 km for a slit height of 1 cm.
- Visible and Near IR solar light must be rejected
- Scattering must be low (1×10^{-6})
 - The ratio of out of band to in band light should be below 0.1%

- signal to noise for a 2 X 2 km spatial element
 - 10:1 at 270 to 290 nm
 - 30:1 throughout the rest of the spectrum
- exposure time-1/7 of a second (1 km of spacecraft motion)
- the state of polarization of the backscattered light
- pointable
- The mechanical design of the spectrograph is such that temperature fluctuations will not change the bandpass by more than 0.1 nm
- Minimize or eliminate High Voltage
- Moving parts must be kept to a minimum
 - CCD in Frame Transfer Mode



FRAME TRANSFER MODE

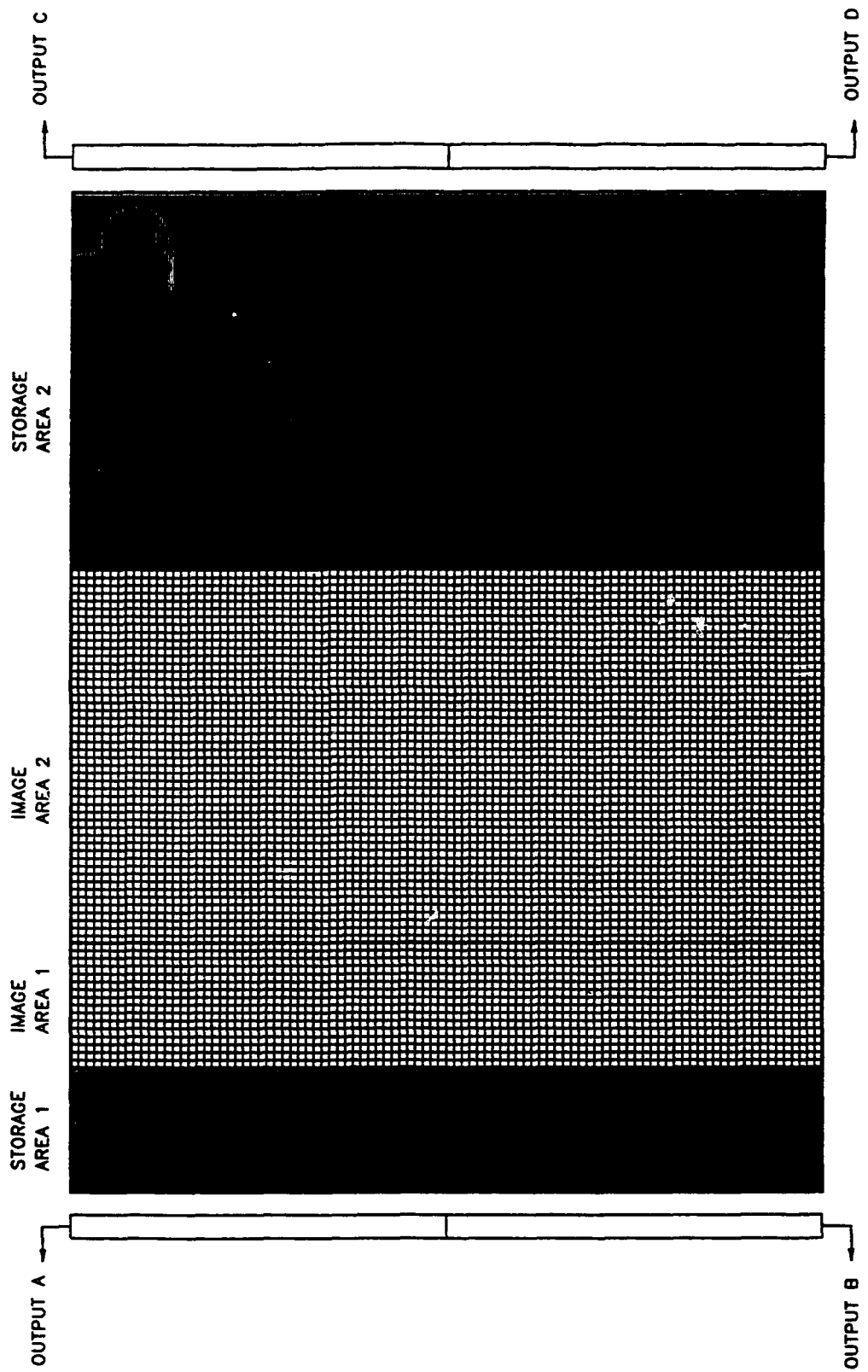
- No mechanical shutter - CCD frame transfer mode
 - image exposed 140 msec
 - quickly transferred to a masked storage area
 - next 140 msec exposure period storage area read out
- signal level $\approx$ 100 counts at 270 nm to nearly 10000 counts at 305 nm.
- Thus, to minimize either spectral smearing (if the transfer from the image to storage area is in the spectral dimension) or spatial smearing (if the transfer from the image to storage area is in the spatial dimension) the transfer should take on the order of 0.5 millisecond or less.

STRAWMAN CCD REQUIREMENTS

All of the following should be stable over a three year mission lifetime with the chips deployed in a sun synchronous 800 km orbit at -30 C.

- READ NOISE-less than 10 cts RMS (goal of 5). Expected pixel read out to be about 70 kpixels/sec to 280 kpixels/sec
- DARK COUNTS - less than 50 counts/sec in a 100 micron X 100 micron pixel at -30 C (equivalent to about 1 ct/sec in a 15 X 15 micron pixel at -30 C)
- QUANTUM EFFICIENCY 15% or better from 270 to 370 nm QE must be stable
- CHARGE TRANSFER EFFICIENCY 0.99999 or better

- VERTICAL TRANSFER TIME FOR ONE LINE 2 microsec or better
- CHIP ARCHITECTURE FOR FLIGHT CCD
 - 1024 X 768 contiguous pixels with no dead space
 - pixel - 18 microns X 18 microns
 - pixel rate/amplifier - near 20 kpixels/sec to 70 kpixels/sec



THE EFFECTS OF RADIATION ON CCDS

- Radiation doses much above 200 Rads/year at 800 km altitude will degrade the performance of the CCD.
- The CCD must be shielded (1 cm of Tantalum)
- Even at 200 Rads/year CCD will deteriorate
 - Dark Count increases
 - Charge Transfer Efficiency (CTE) decreases

- These effects must be quantified
 - NASA Cassini-JPL tests
 - With sufficient shielding probably not a problem in first year of mission
 - May or may not effect sensitivity in 2nd and 3rd year in the 270 to 290 nm region
 - Having two identical spectrographs may mitigate this problem
- Continue to study this problem

SUMMARY

- SPECTRAL RESOLUTION 2 nm from 270 to 350 nm
- SPATIAL RESOLUTION 2 X 2 km from 800 km orbit
- EXPOSURE TIME 1/7 sec
- SIGNAL TO NOISE
 - 10:1 at 270 nm
 - 30:1 from 290 to 370 nm
- DYNAMIC RANGE
 - Flatten Solar Spectrum
 - 12 bits (4000)
- INTERNAL SCATTERING - less than 10^{-6}
- POLARIZATION 0,45, and 90 degrees

- FIELD OF VIEW 100 km Cross Track
 - Pointable - 30 degrees of nadir
- MECHANICAL AND THERMAL STABILITY
 - Center of bandpass must be known to 0.1 nm
- CCD DETECTOR
 - Cooled to -30 C
 - Read Noise below 10 counts RMS
 - QE 15% from 270 to 370 nm
 - CTE 0.99999 or better for first year of operation
 - Shielded - 200 Rads /year
 - Data Rate 15 to 300 kpixels/sec (15 Mbits/sec)
 - Data Storage 2 Gbits - 1000 km



OPTICAL DESIGN

D. J. GUTIERREZ



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Technology Center

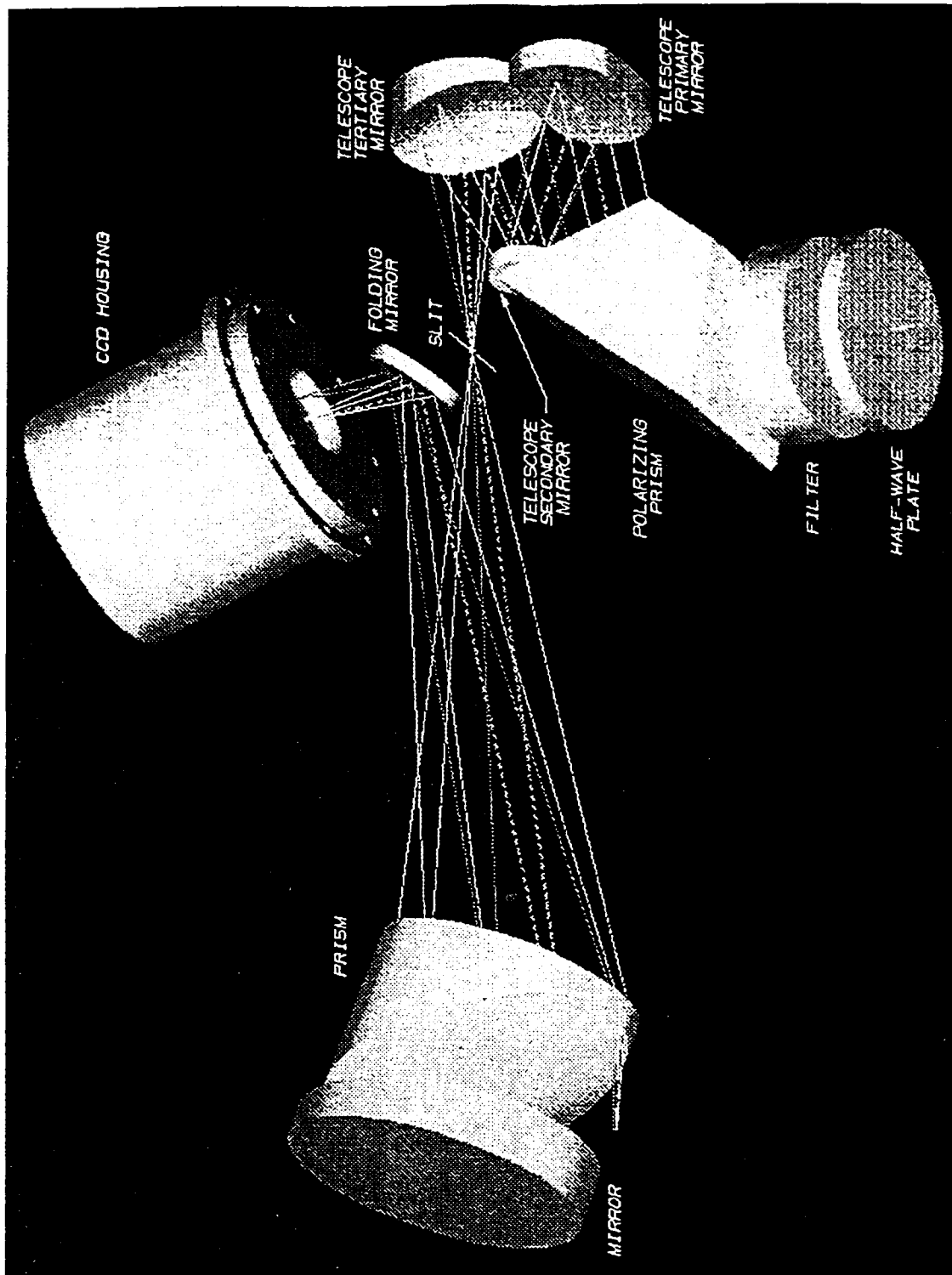
HIROIG
System Requirement Review

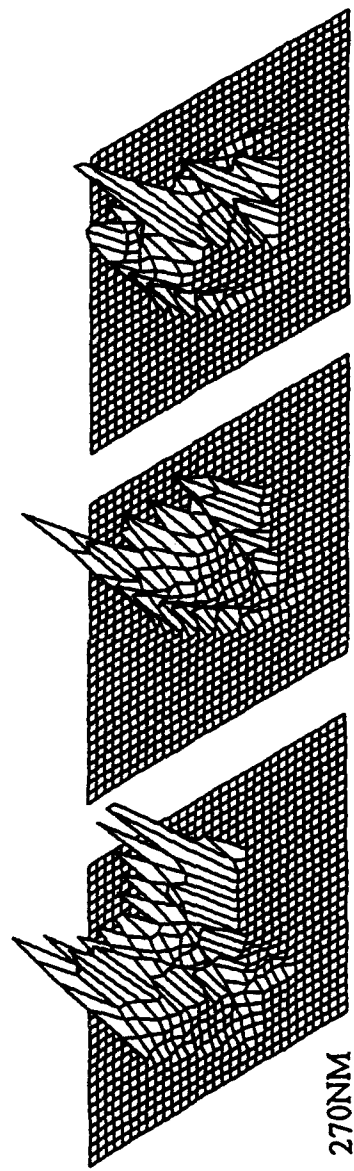
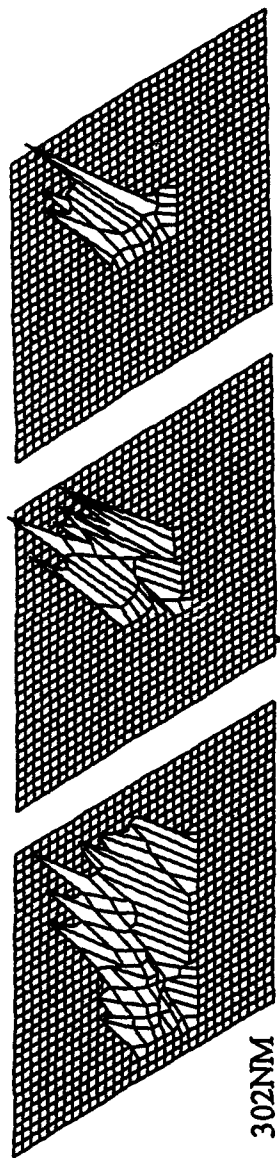
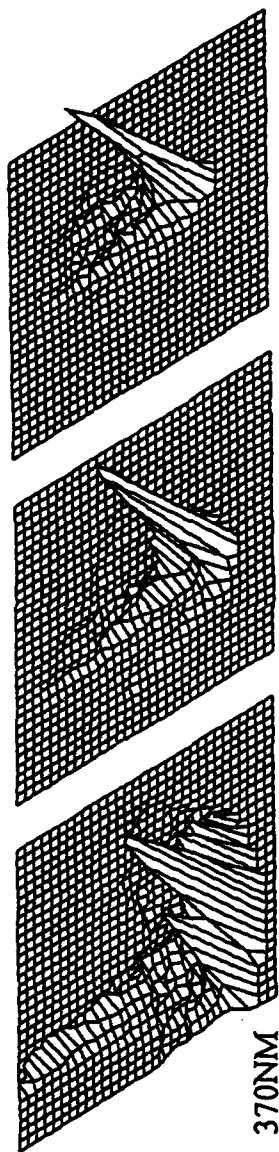
Feb. 17, 1993
Dave Gutierrez

OPTICAL DESIGN

- **OPTICAL LAYOUT -- PRISM DISCUSSION**
- **IMAGING PERFORMANCE**
- **RESPONSIVITY**
- **SIGNAL RATES**

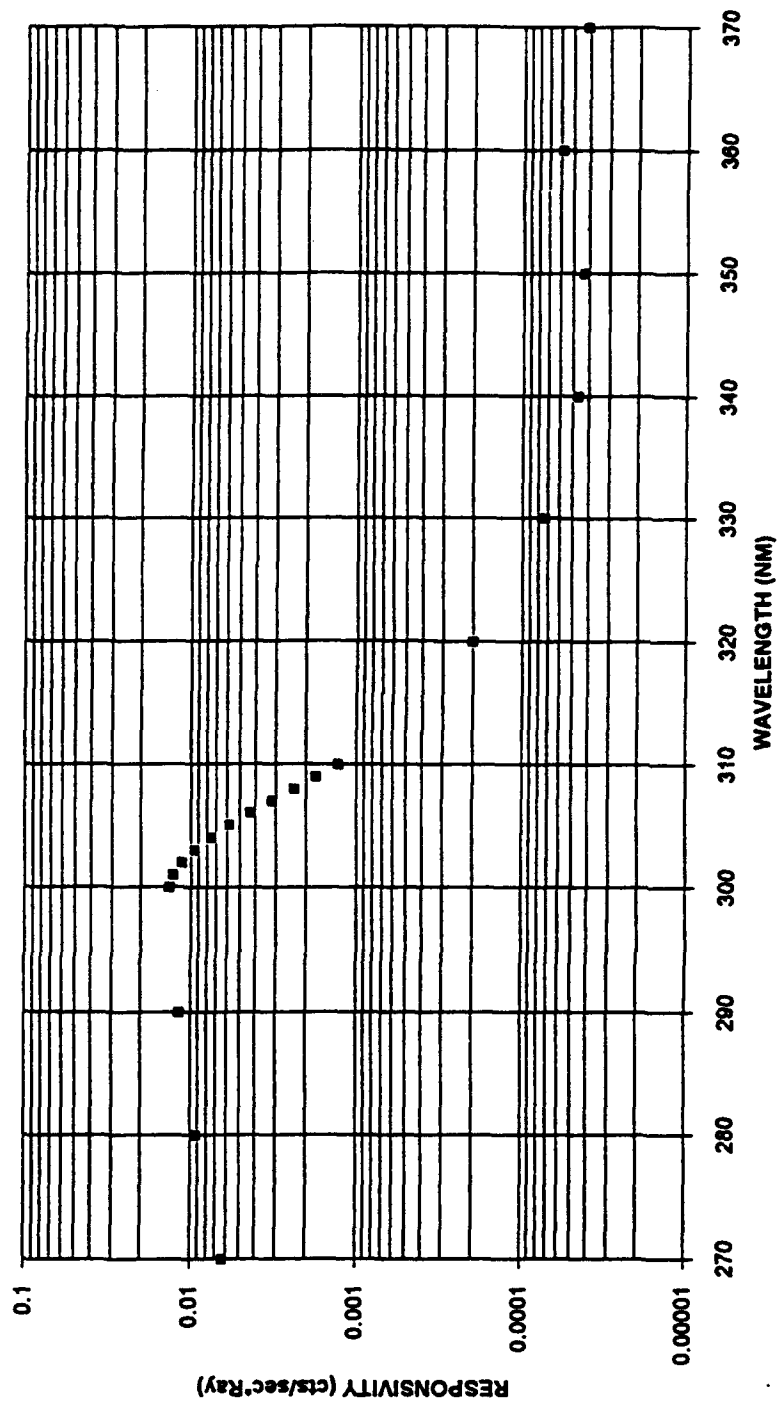
OPTICAL LAYOUT



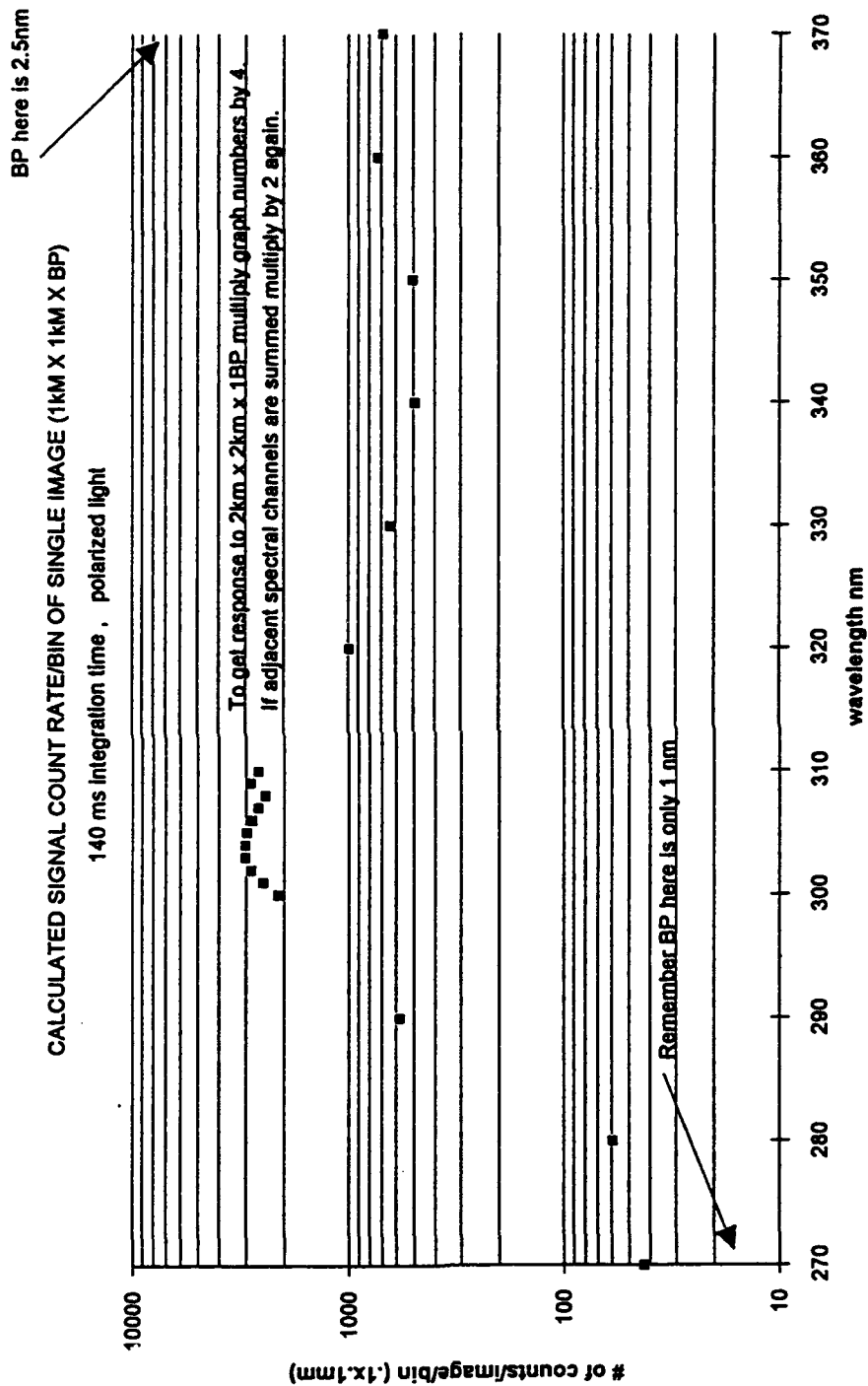


IMAGING PERFORMANCE

CALCULATED RESPONSIVITY OF HIROIG



RESPONSIVITY

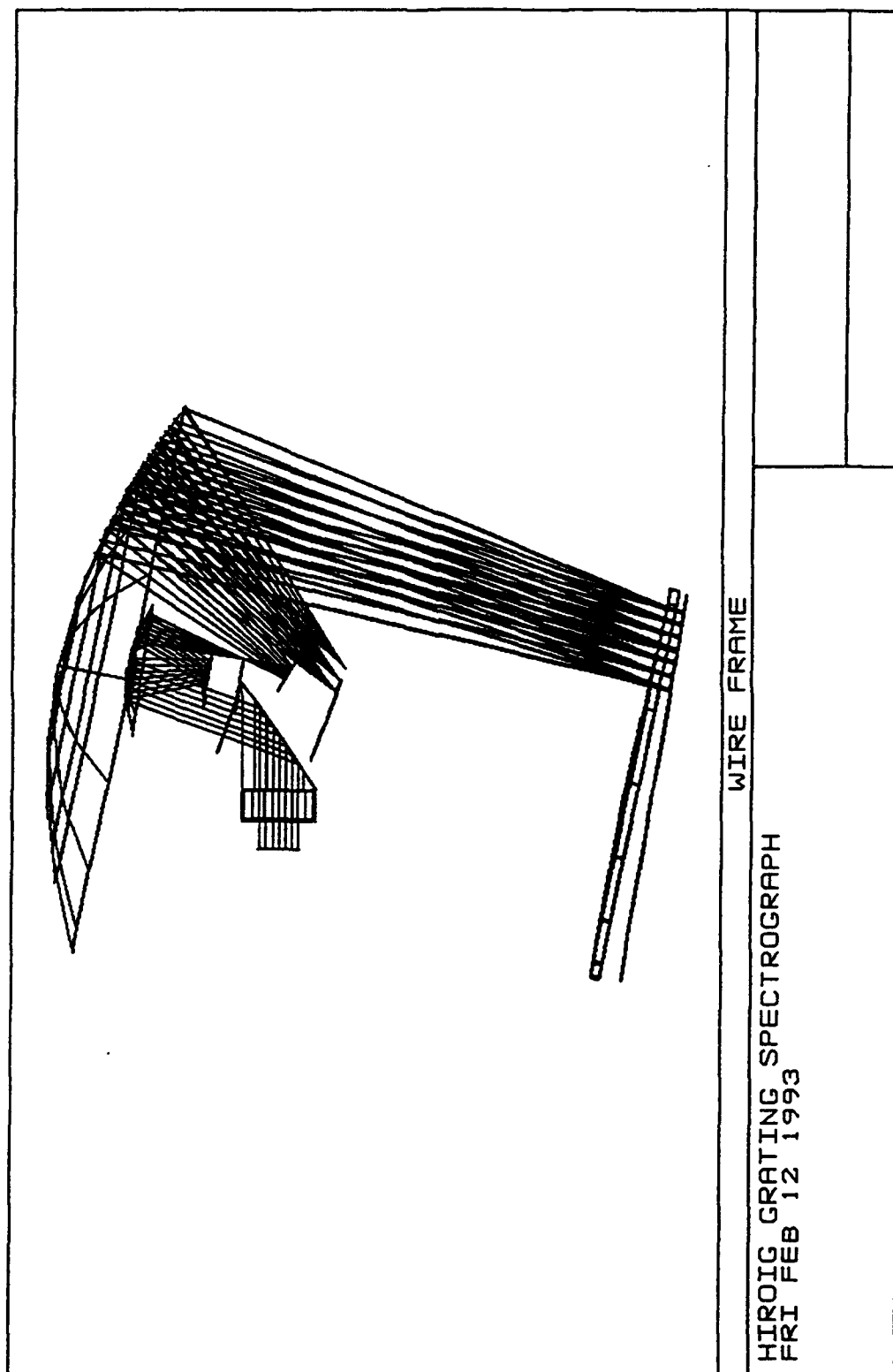


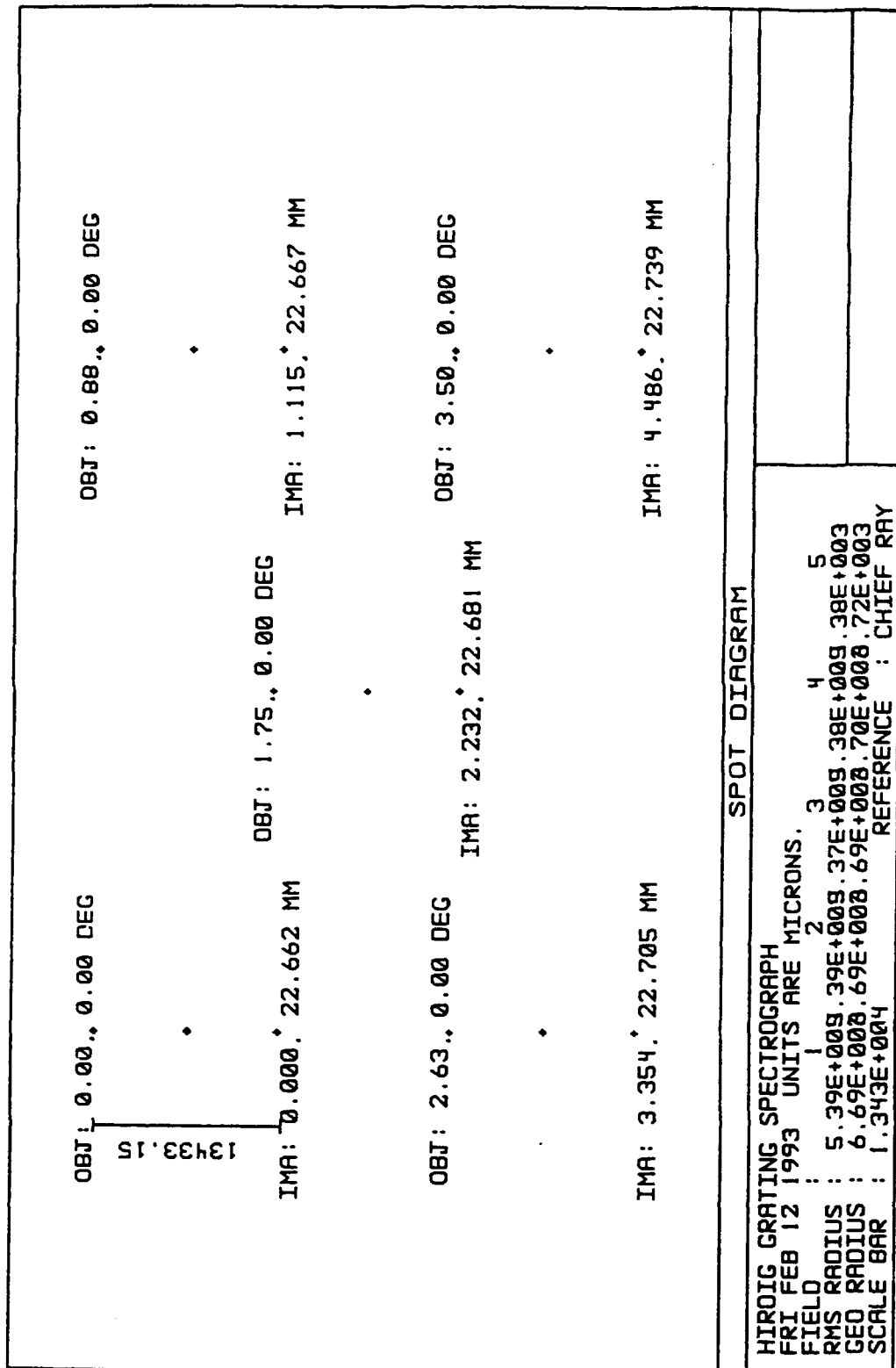
SIGNAL RATES



OPTICAL DESIGN

G. S. ROSSANO





SPOT DIAGRAM

HIROIG GRATING SPECTROGRAPH

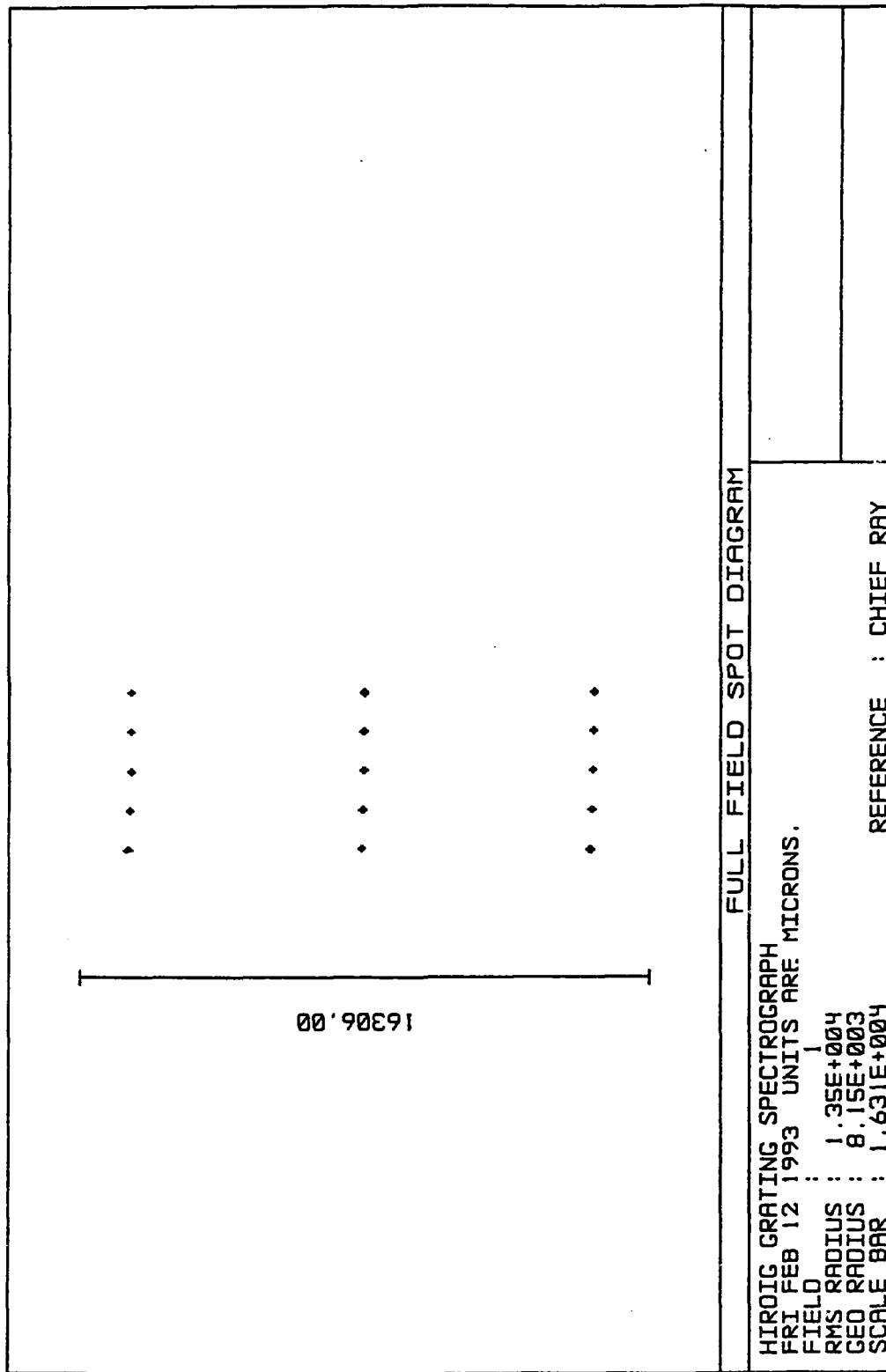
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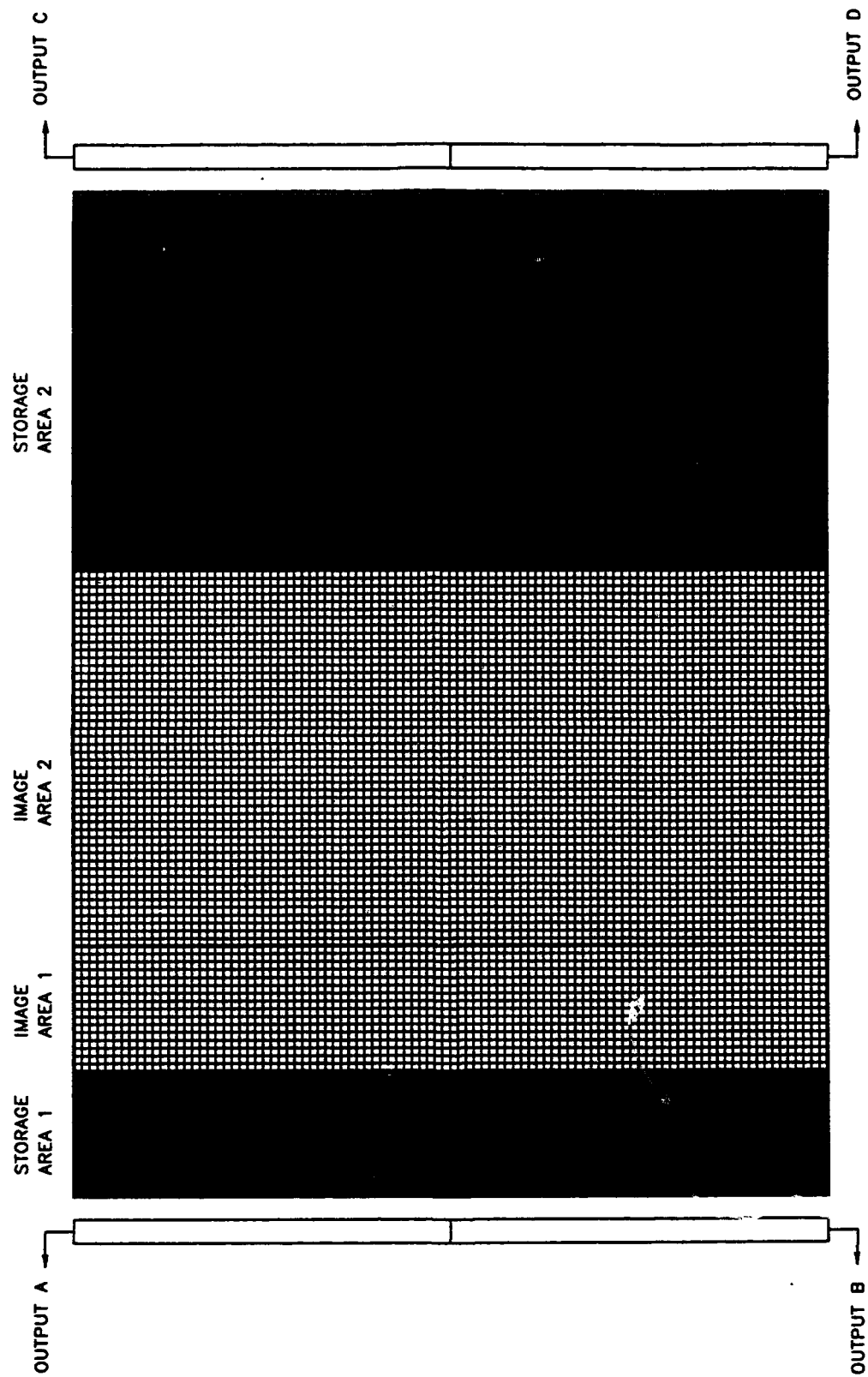
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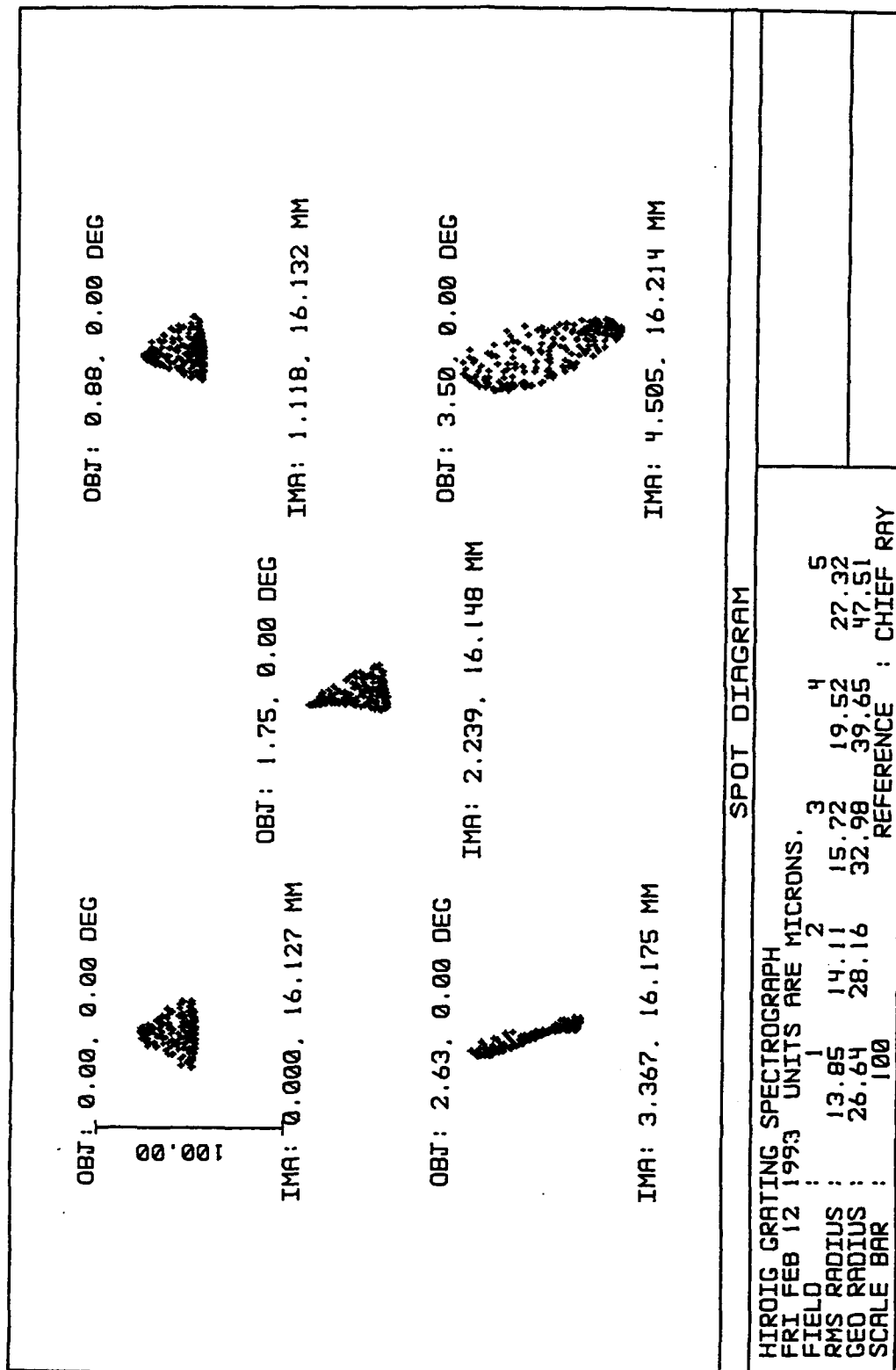
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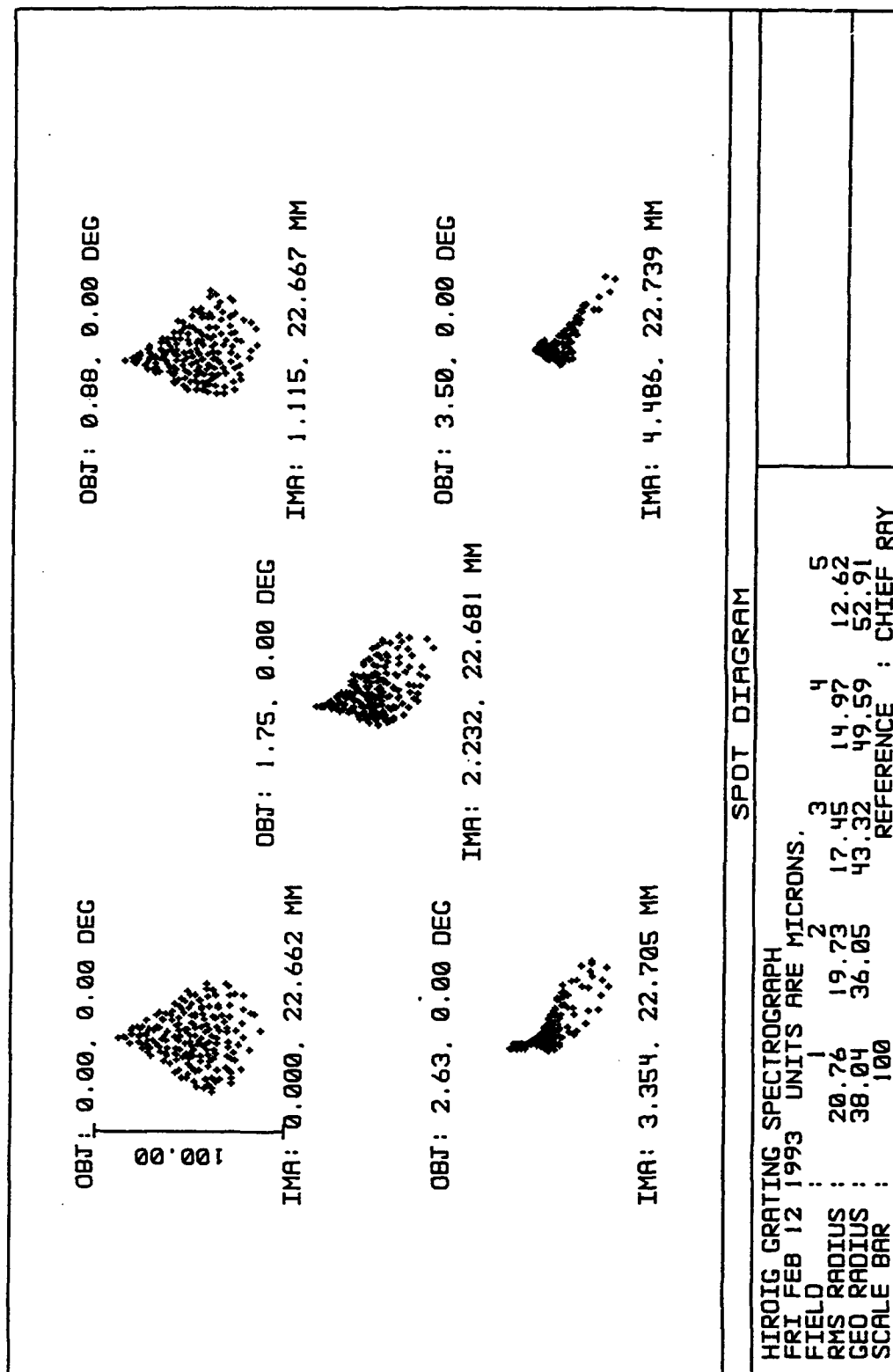
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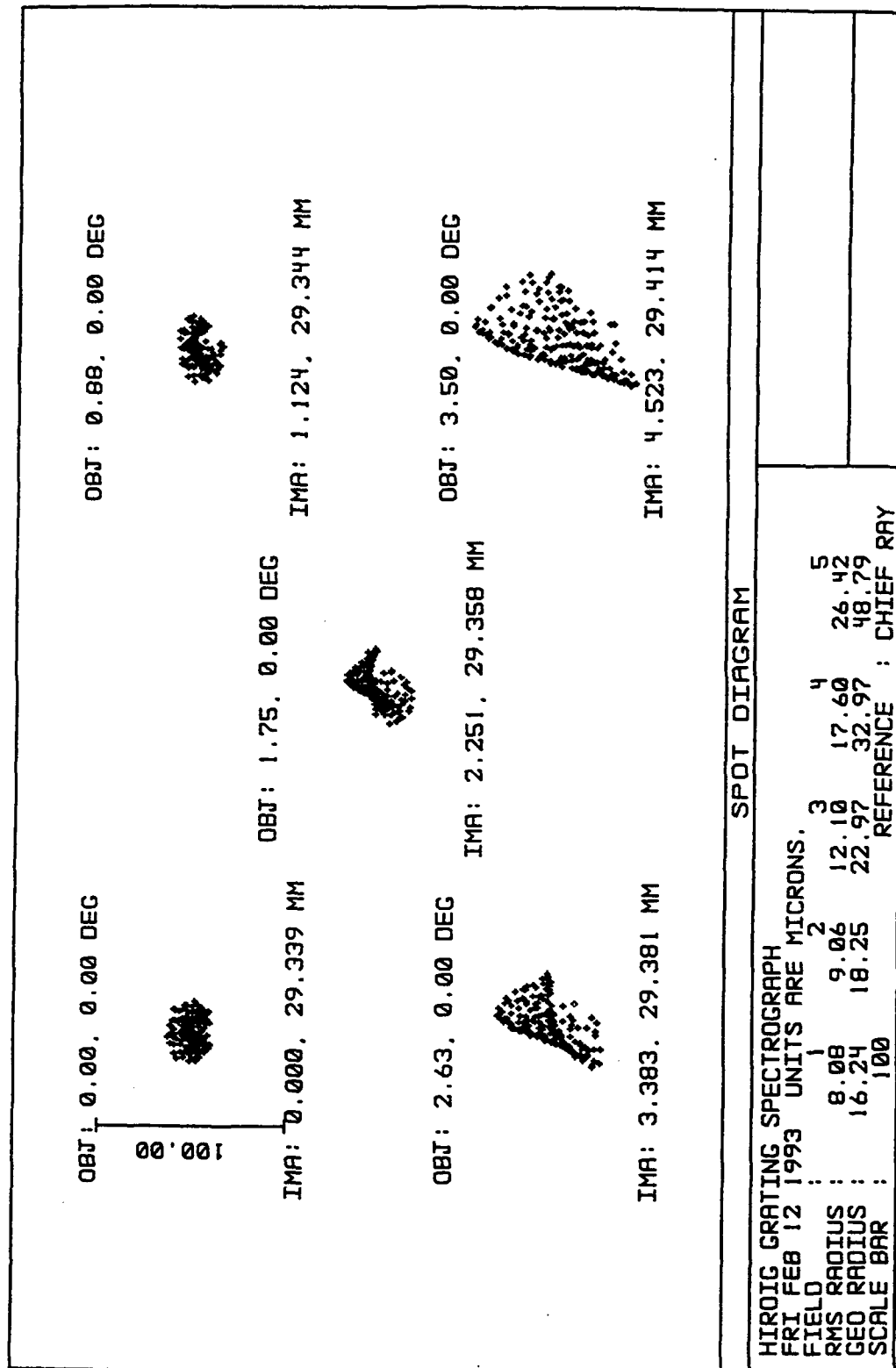
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HIROIG SYSTEM REQUIREMENTS REVIEW

Feb 17, 1993

MECHANICAL DESIGN

M. G. SIVJEE



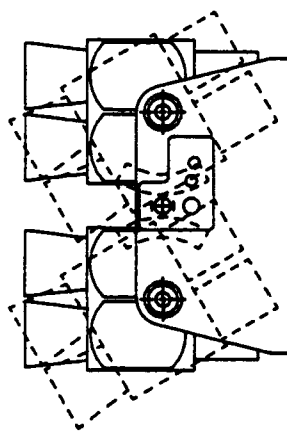
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HIROIG System Requirement Review

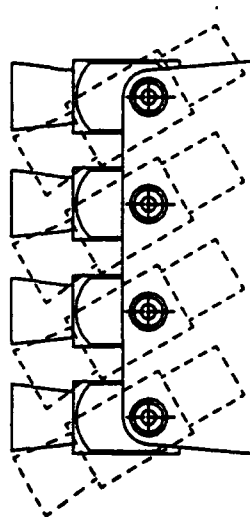
Feb. 17, 1993
M. G. Sivjee

HIROIG MECHANICAL CONSIDERATIONS

- FOUR SPECTROGRAPHS CO-ALIGNED TO WITHIN $\pm 0.007^\circ$ (25 ARC-SEC)
- SWEEP MOTION CAPABILITY OF $\pm 30^\circ$
- PRECISION MOUNTING AND ALIGNMENT OF OPTICS
- COOLING OF CCD's
- RADIATION SHIELDING OF CCD's



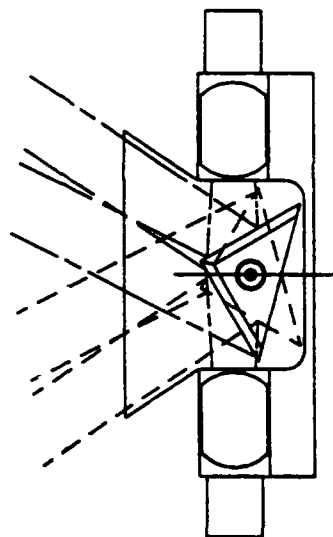
TWO LINKED PAIRS



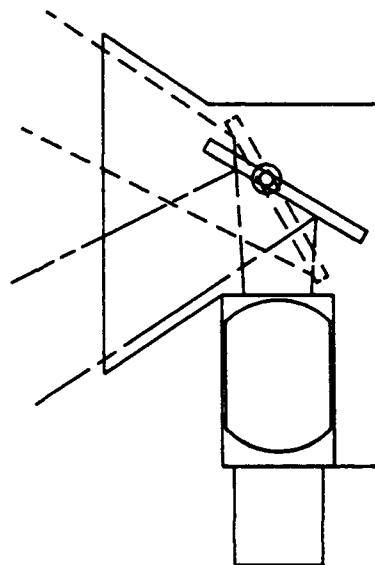
FOUR MECHANICALLY
LINKED INSTRUMENTS

DIFFICULT TO MAINTAIN CO-ALIGNMENT

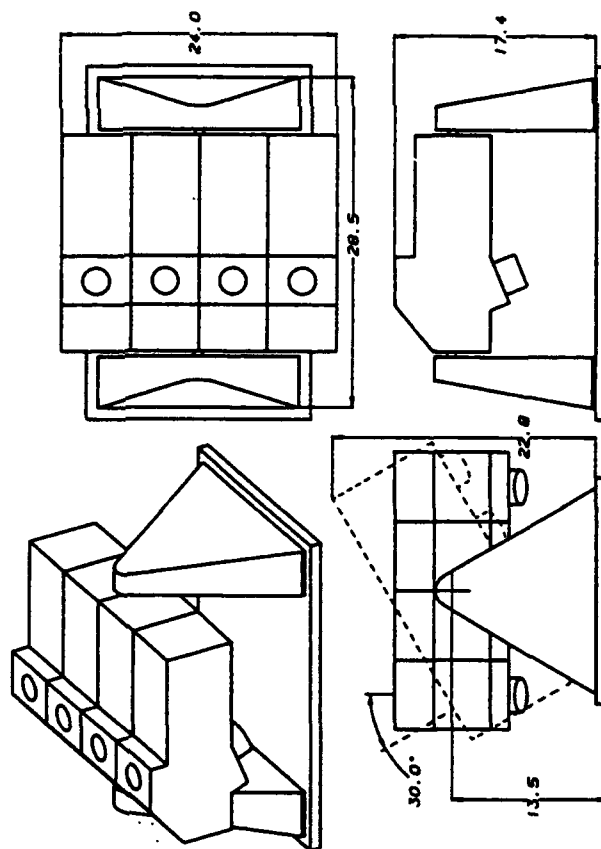
BASE MUST BE RIGID AND MOUNTED TO THE SPACECRAFT AT ONLY 3 POINTS SO THAT SPACECRAFT THERMAL INSTABILITY DOES NOT CHANGE INSTRUMENT CO-ALIGNMENT



FOUR POINTING MIRRORS
 INSTRUMENTS FIXED TO BASE
 FOUR SLIGHTLY DIFFERENT CCD IMAGES
 BECAUSE OPTICAL ELEMENTS ARE REVERSED
 RELATIVELY EASY TO CO-ALIGN



ONE LARGER INSTRUMENT
 SINGLE POINTING MIRROR
 ROTATING POLARIZER
 REQUIRES CCD AND ELECTRONICS
 TO OPERATE MANY TIMES FASTER

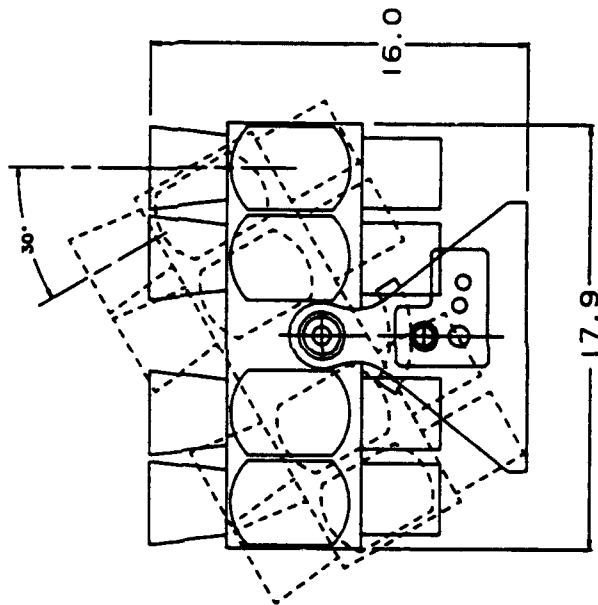
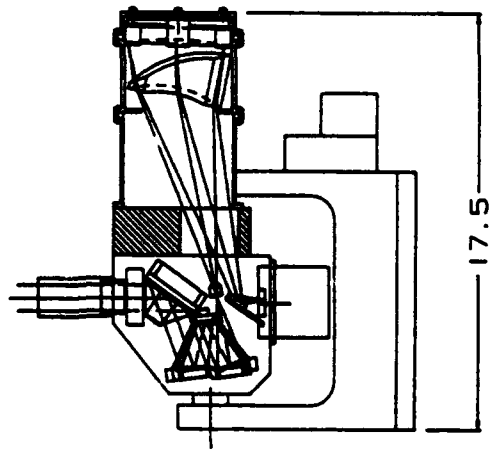
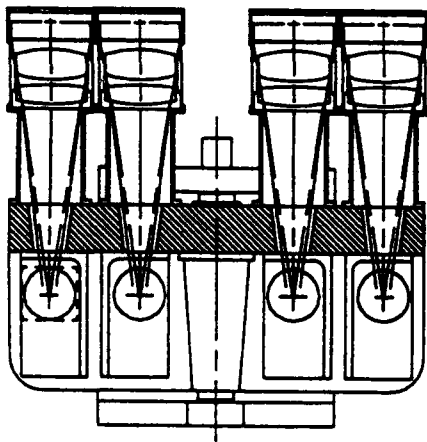
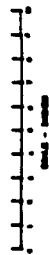


SCAN FOUR UNITS ON SINGLE PIVOT

HIGH CG AND PIVOT HEIGHT
FOUR INDIVIDUAL MODULES FOR EASIER ALIGNMENT
DOES NOT DEPEND ON MOUNT ISOLATION FROM THE
SPACECRAFT

HIROIG

HIGH RESOLUTION OZONE IMAGER





DATA PROCESSING UNIT

D. J. MABRY

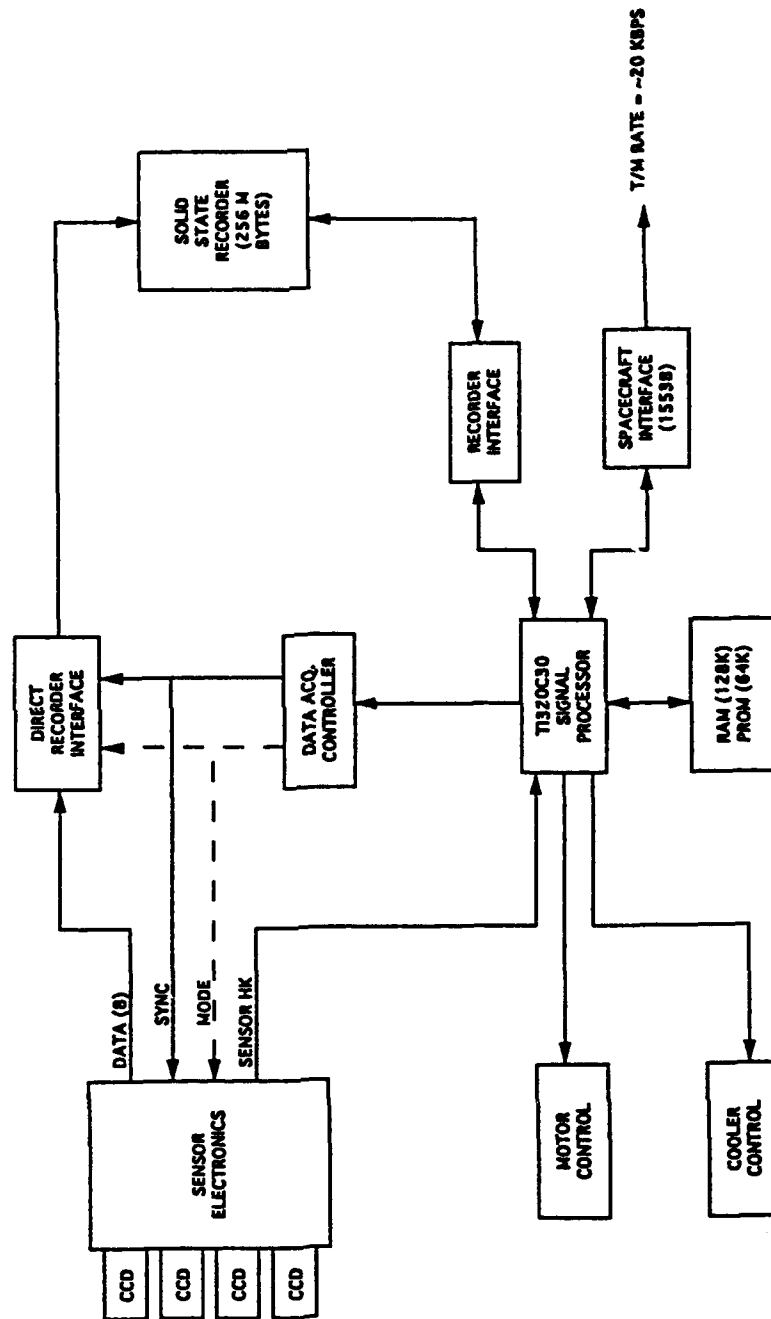
HIROIG DPU Requirements

The HIROIG Data Processing Unit (DPU) should provide capabilities to:

- accept images of 180 x 260 pixels (12 bits/pixel) from 4 imagers simultaneously at a frame rate of 7 images/second (15.7 Mbits/sec)
- provide storage on-board for 2 minutes of continuous image acquisition (225 Mbytes)
- provide data processing capabilities to reduce 225 Mbyte recorder content to fit within 100 Mbits/orbit telemetry allocation
- provide a "low noise" mode of operation during image exposure
- provide controls for coolers and motor(s). Accept, compile, and monitor cooler, motor, CCD, and power supply housekeeping data
- provide protected command interface with spacecraft, including capabilities for modifying flight software or table data

Dan Mabry
17 February 1993

HIROIG DPU Overview



HIROIG DPU Modes

- **Exposure Mode**

- Interleaved CCD images pass directly from signal conditioning electronics to recorder under hardware control
- Processing electronics operate in "low noise" mode to reduce recorded image contamination

- **Housekeeping Mode**

- Processing electronics become active for ~1 msec every 140 msec while CCD image is transferred between active and masked area
- Operations performed are cooler/heater monitoring, image header and trailer generation, recorder memory management
- Software algorithms in conjunction with knowledge of available recorder space and acquisition parameters determine whether next mode is Exposure or Processing

HIROIG DPU Modes (continued)

- Data Processing Mode
 - CCD data acquisition suspended during data processing
 - Primary function: "reduce" 225 Mbytes of recorder images to fit into 1 or more telemetry orbits (100 Mbits/orbit)
 - For non-recurring observations, recorder data can be minimally compressed and telemetered over several orbits
 - For recurring observations, compression factor (CF) of 20 is needed to empty recorder for next observation. Compression algorithms are being evaluated.

Dan Mabry
17 February 1993

HIROIG DPU Theory of Operation

- Ground command specifies look direction, start time and duration for observation
- DPU points imagers via motor controls, then waits for start of observation while monitoring housekeeping data
- DPU programs Data Acquisition Controller when observation time arrives, then the DPU toggles between Exposure and Housekeeping modes while images pass to recorder
- At end of exposure, Processing mode is entered to begin data compression and telemetry creation

HIROIG Solid State Recorder

Model: SEAKR Engineering SESSM - 1.9GR

Storage, Megabits: 1.9

Size, inches: 10 x 6.8 x 6.7

Data Channels: 8 bit parallel (input/output)
serial control

Data Rates:

Input Data: 25 Mbps

Output Data: 25 Mbps

Control: 125 Kbps

Input Voltage: 22 VDC to 36 VDC

Power:

Standby: 5.75 Watts

Operational: < 15 Watts

Bit Error Rate: < 1 x 10E-10



MANAGEMENT AND SCHEDULES

J. A. Stein



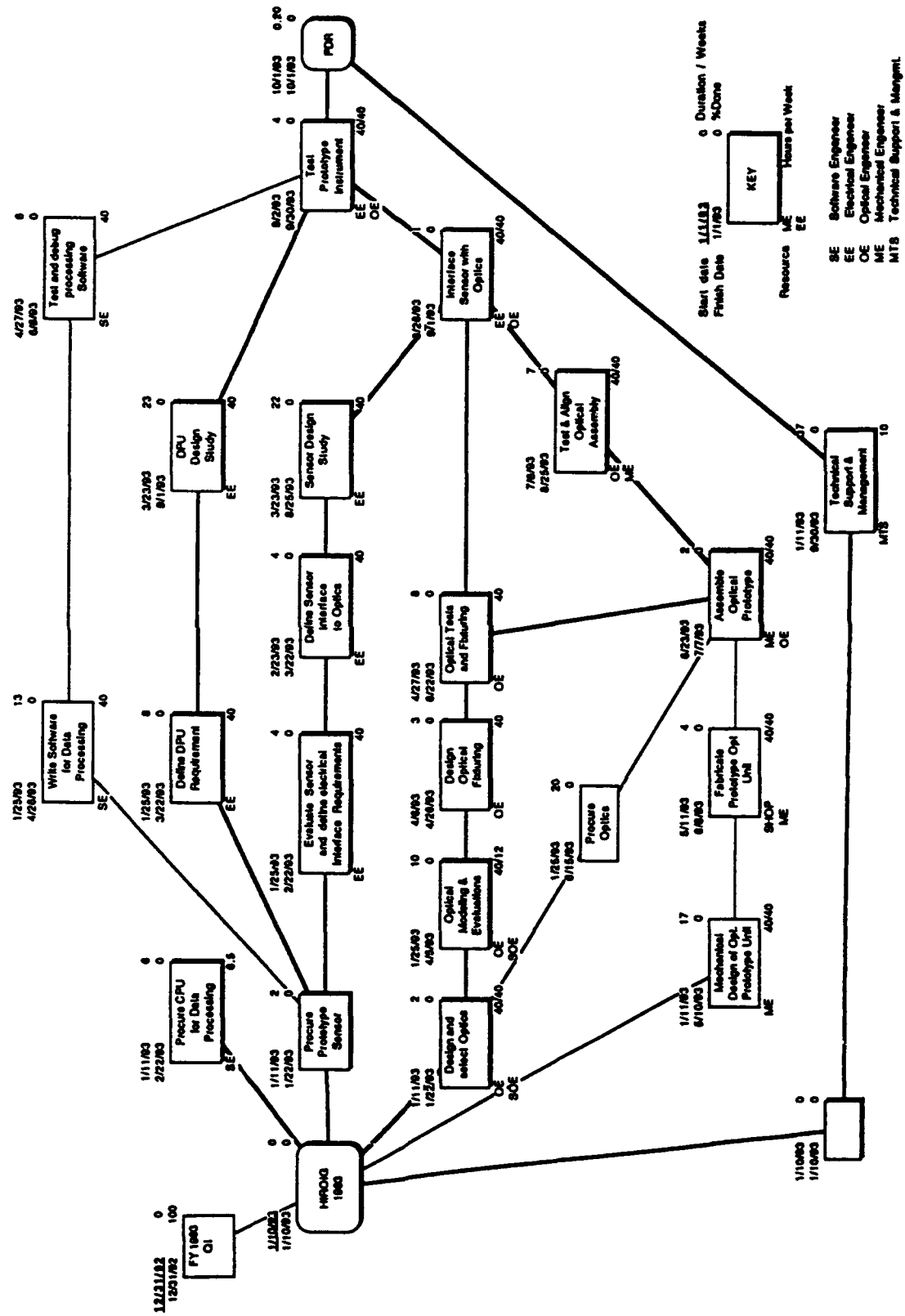
THE AEROSPACE CORPORATION
Space and Environment
Technology Center

HIROIG System Requirement Review

Feb. 17, 1993
Joe Stein

OVERVIEW

1. PROJECT SCHEDULE
2. PROJECTED FUNDING REQUIREMENT
3. FUNDING ALLOTMENT BY ENGINEERING CATEGORIES
4. PROJECTED SPENDING RATE & EXPENDITURES TO DATE



HIGH RESOLUTION OZONE IMAGER (HIROIG) PROTOTYPE SYSTEM SCHEDULE

	THE AEROSPACE CORPORATION Space and Environment Technology Center	HIROIG System Requirement Review	Feb. 17, 1993 Joe Stein
MANPOWER ALLOTMENT BY ENGINEERING CATEGORY (Man Weeks) For Quarters 2 to 4 FY 1993			
OPTICAL ENGINEERING	50		
MECHANICAL ENGINEERING	44		
ELECTRICAL ENGINEERING	49		
SOFTWARE ENGINEERING	20		
SCIENTIFIC STUDIES	30		
MECHANICAL FABRICATION	8		
MANAGEMENT	10		



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**HIROIG
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PROJECTED FUNDING REQUIREMENT

PRELIMINARY STUDIES IN FIRST QUARTER OF FY 1993	\$ 76,300
PROJECTED LABOR FOR REMAINING FY 1993	\$616,200
PARTS AND MATERIAL	\$110,000
TOTAL PROJECTED COST FOR FY 1993	\$802,500



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HIROIG LABOR COST SCHEDULE FY 1993

Starting	Plan Costs	Plan Income	Actual Costs	Actual Income	Ending	Plan Cumulative	Actual Cumulative
12/1/92	76300.00	0.00	76300.00	0.00	1/1/93	-76300.00	-76300.00
1/1/93	54514.36	0.00	40400.00	0.00	2/1/93	-130814.36	-116700.00
2/1/93	81525.11	0.00	0.00	0.00	3/1/93	-212339.46	-116700.00
3/1/93	98022.85	0.00	0.00	0.00	4/1/93	-310362.31	-116700.00
4/1/93	92624.95	0.00	0.00	0.00	5/1/93	-403187.26	-116700.00
5/1/93	74293.79	0.00	0.00	0.00	6/1/93	-477481.05	-116700.00
6/1/93	60348.42	0.00	0.00	0.00	7/1/93	-537829.47	-116700.00
7/1/93	60249.54	0.00	0.00	0.00	8/1/93	-598079.01	-116700.00
8/1/93	60194.24	0.00	0.00	0.00	9/1/93	-658273.25	-116700.00
9/1/93	34228.34	0.00	0.00	0.00	10/1/93	-692501.59	-116700.00
10/1/93	0.00	0.00	0.00	0.00	11/1/93	-692501.59	-116700.00



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HIROIG System Requirement Review

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HIROIG TOTAL COST SCHEDULE FY 1993

Starting	Plan Costs	Plan Income	Actual Costs	Actual Income	Ending	Plan Cumulative	Actual Cumulative
12/1/92	76300.00	0.00	76300.00	0.00	1/1/93	-76300.00	-76300.00
1/1/93	143687.34	0.00	40400.00	0.00	2/1/93	-219987.34	-116700.00
2/1/93	81028.90	0.00	0.00	0.00	3/1/93	-301016.24	-116700.00
3/1/93	113138.89	0.00	0.00	0.00	4/1/93	-414155.13	-116700.00
4/1/93	102019.57	0.00	0.00	0.00	5/1/93	-516174.70	-116700.00
5/1/93	77280.70	0.00	0.00	0.00	6/1/93	-593455.40	-116700.00
6/1/93	63219.81	0.00	0.00	0.00	7/1/93	-656675.22	-116700.00
7/1/93	58640.31	0.00	0.00	0.00	8/1/93	-715515.53	-116700.00
8/1/93	52757.72	0.00	0.00	0.00	9/1/93	-768273.25	-116700.00
9/1/93	34228.34	0.00	0.00	0.00	10/1/93	-802501.59	-116700.00
10/1/93	0.00	0.00	0.00	0.00	11/1/93	-802501.59	-116700.00

TECHNOLOGY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Technology Operations supports the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual Technology Centers:

Electronics Technology Center: Microelectronics, solid-state device physics, VLSI reliability, compound semiconductors, radiation hardening, data storage technologies, infrared detector devices and testing; electro-optics, quantum electronics, solid-state lasers, optical propagation and communications; cw and pulsed chemical laser development, optical resonators, beam control, atmospheric propagation, and laser effects and countermeasures; atomic frequency standards, applied laser spectroscopy, laser chemistry, laser optoelectronics, phase conjugation and coherent imaging, solar cell physics, battery electrochemistry, battery testing and evaluation.

Mechanics and Materials Technology Center: Evaluation and characterization of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; development and analysis of thin films and deposition techniques; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; development and evaluation of hardened components; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion; spacecraft structural mechanics, spacecraft survivability and vulnerability assessment; contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; lubrication and surface phenomena.

Space and Environment Technology Center: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation; propellant chemistry, chemical dynamics, environmental chemistry, trace detection; atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, and sensor out-of-field-of-view rejection.