EARTH OBSERVING SYSTEM MICROWAVE LIMB SOUNDER:

A VIEW FROM THE FRONT

PRESENTED AT THE

SECOND INTERNATIONAL CONFERENCE ON SPACE THZ TECHNOLOGY

CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY
PASADENA, CALIFORNIA

FEBRUARY 26, 1991

BY
PETER H. SIEGEL

Earth **O**bserving **S**ystem
Microwave **L**imb **S**ounder

United States
Global Change
Research Program

EOS GOALS

1. LONG TERM RELIABLE MEASUREMENTS OF GEOPHYSICAL & BIOLOGICAL VARIABLES SO THAT GLOBAL, REGIONAL & LOCAL CHANGES CAN BE DOCUMENTED OVER A 15 YEAR PERIOD

2. IDENTIFICATION OF THE MOST IMPORTANT PROCESSES IN EARTH SYSTEM SCIENCE

3. IMPROVEMENTS IN PREDICTIVE MODELS OF THE EARTH'S DYNAMIC PROCESSES

EOS INVESTIGATIONS

1. INTERDISCIPLINARY INVESTIGATIONS
Climatology, Earth Resources, Biological Monitors

2. SPECIFIC SCIENCE INSTRUMENTS
Imaging, Atmospheric Chemistry, Radiance

3. FACILITY INSTRUMENTS
Wind speed & direction, temperature, humidity, cloud cover, IR imaging

---

EOS INSTRUMENTS ORGANIZED BY TYPE

SURFACE IMAGERS
- CERES
- EOSP
- HIMSS
- HIRIS
- ITIR
- MISR
- MODIS

TROPOSPHERIC SOUNDERS
- AIRS
- HIMSS
- MODIS

STRATOSPHERIC CHEMISTRY
- MLS
- HIRDLS
- SAFIRE
- SAGE
- SWIRLS

RADAR/LIDAR
- ALT
- GGI
- GLRS
- LAWS
- STIK SCAT
- EOS SAR

TROPOSPHERIC CHEMISTRY
- LIS
- MOPITT
- TRACER
- TES

SOLAR IRRADIANCE
- ACRIM
- SOLSTICE

SOLAR-TERRESTRIAL INTERACTIONS
- GOS
- IPEI
- XIE

CURRENT EOS PLATFORM STATISTICS AS OF 2/91

LAUNCH DATES: EOS-A 12/98 EOS-B 6/01
12/03 6/06
12/08 6/11

LAUNCH VEHICLE: TITAN IV

ORBIT: SUN SYNCHRONOUS-705KM 98.2 DEG INCL.

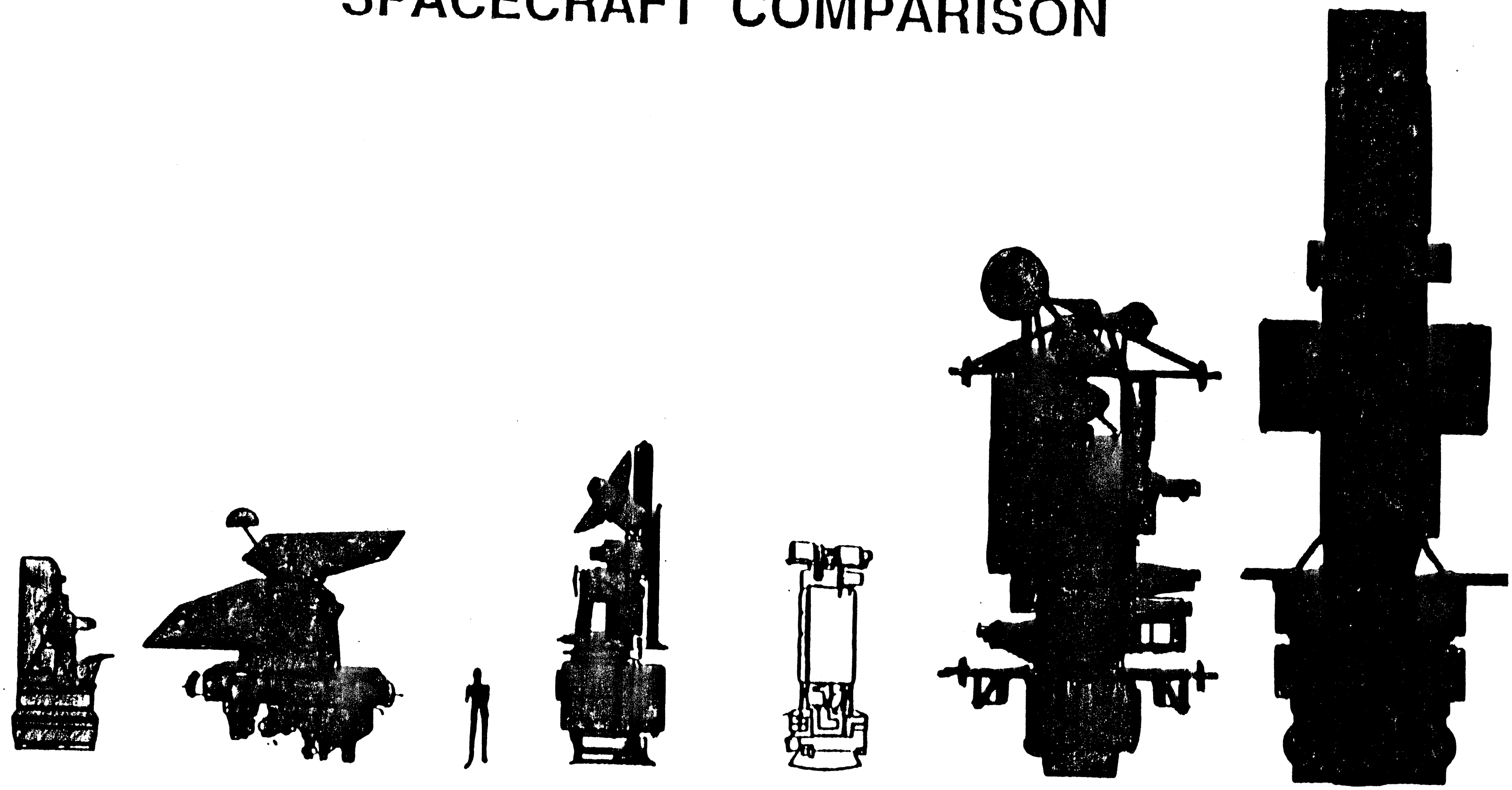
MASS=3500kg • POWER=3200W • DATA RATE=30 Mb/sec
2,600 Gb/day

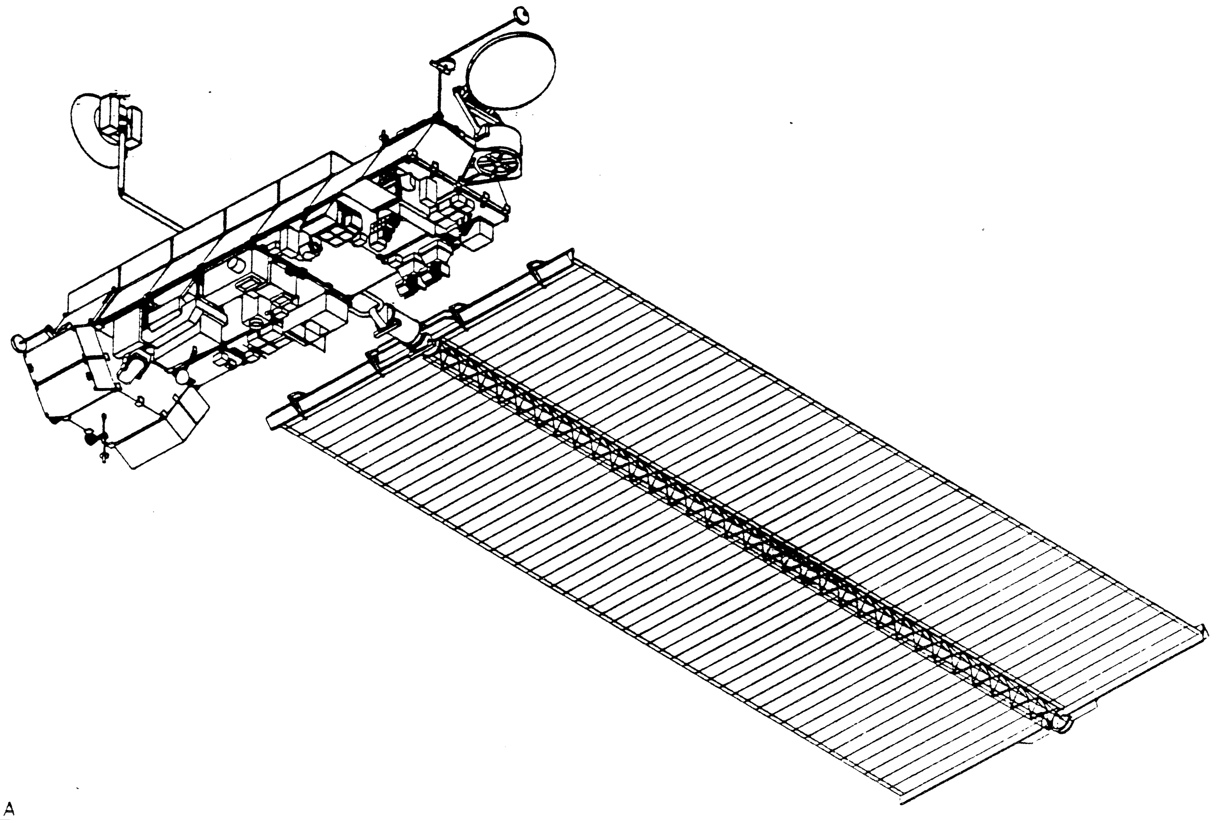
PAYLOADS: EOS-A 11 INSTRUMENTS
AIRS/AMSU-ASTER-CERES-EOSP-HIRDLS-LIS
MIMR-MISR-MODIS-MOPITT-STIK SCAT

EOS-B 14 INSTRUMENTS PLUS EOS-SAR
SOLSTICE-HIRDLS-MLS-SAFIRE-SAGE-SWIRLS
TES-LAWS-ALT-GLRS-GGI-GOS-IPEI-XIE

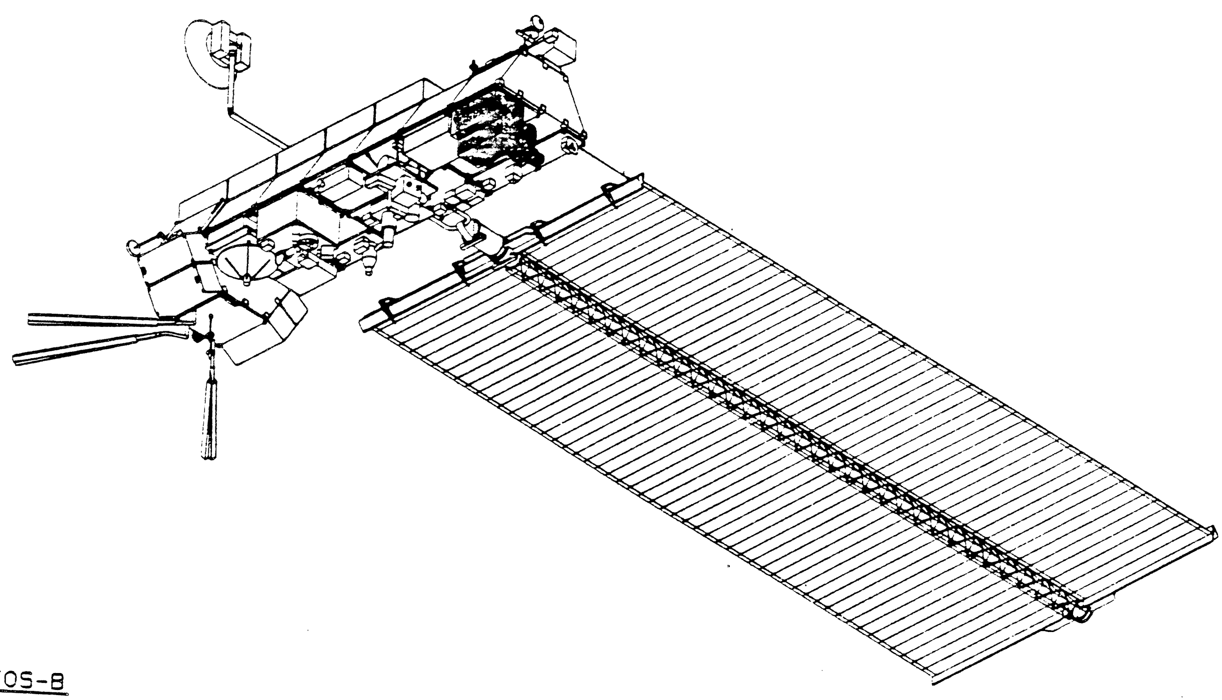
TOTAL COST: 30 BILLION OVER 20 YEARS
2-3 BILLION/PLATFORM (6 TOTAL) PLUS SCIENCE

APPROXIMATE SPACECRAFT COMPARISON



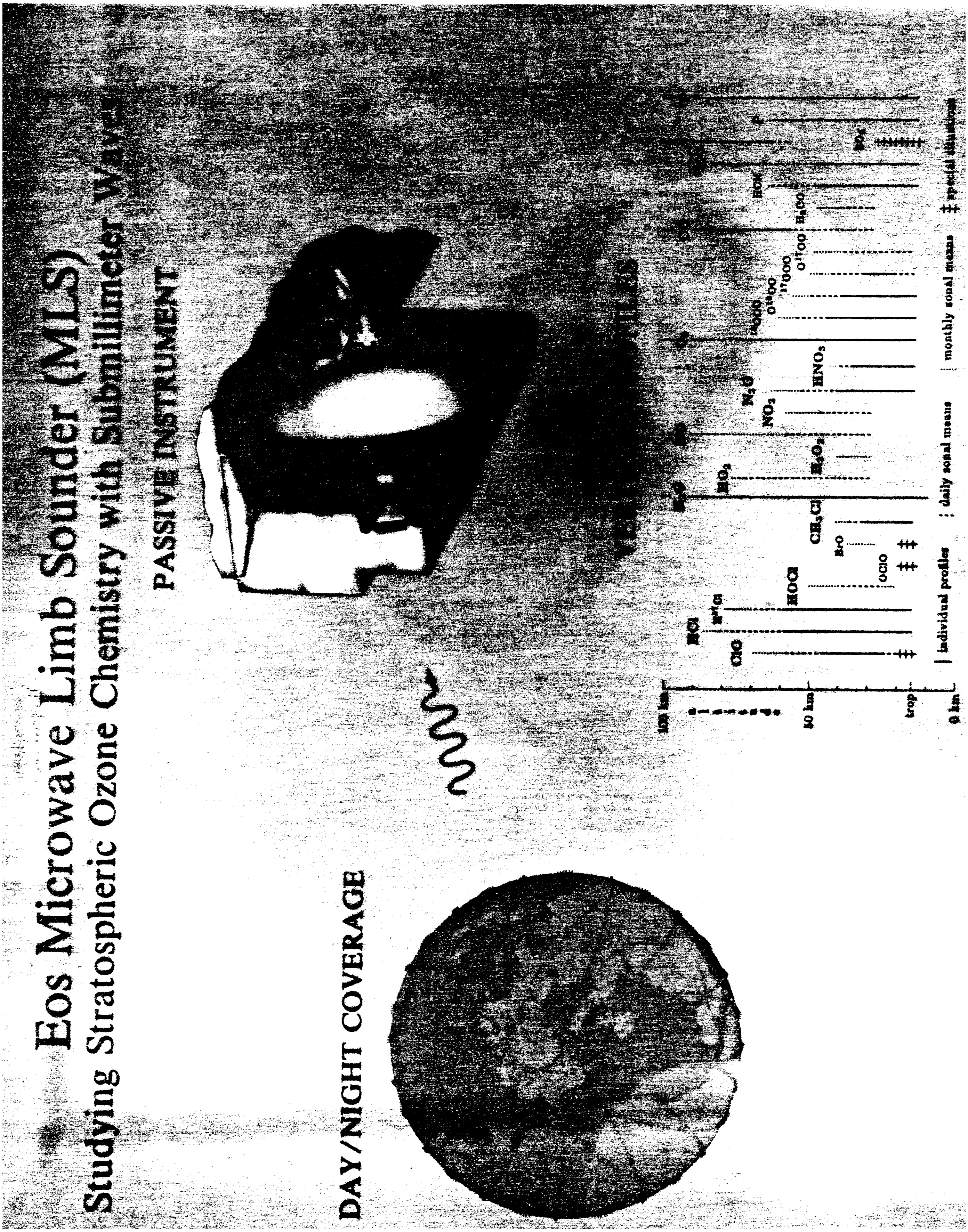


EOS-A



EOS-B

Figure 5. EOS-A and EOS-B Platforms


Eos Microwave Limb Sounder (MLS)
Studying Stratospheric Ozone Chemistry with Submillimeter Waves
PASSIVE INSTRUMENT
DAY/NIGHT COVERAGE
100 km
50 km
trop
0 km
ClO
HCl
HOCl
OClO
BrO
CH3Cl
HO2
H2O2
NO2
N2O
HNO3
individual profiles
daily zonal means
monthly zonal means
special situations

EOS-MLS PRIMARY OBJECTIVES

MONITOR/STUDY GLOBAL CHANGE IN STRATOSPHERE/MESOSPHERE

CRITICAL GLOBAL MONITORING OF OZONE CHEMISTRY

MONITORING OF HETEROGENEOUS CHEMISTRY PERTURBATIONS

INSTRUMENT FEATURES

HIGH SENSITIVITY, HIGH SPECTRAL RESOLUTION HETERODYNE RADIOMETERS IN MILLIMETER & SUBMILLIMETER WAVE BANDS

RADIATIVE COOLING OF DETECTORS TO 90K

COMPLETE SPECTRUM EVERY 0.6 SEC

MODULAR PACKAGING

HERITAGE FROM PRIOR & ON-GOING MLS EXPERIMENTS
BALLOON, AIRCRAFT, UARS

EOS-MLS Vital Stats

Mass=450 kG
Power=650W
Cost (NAR)=320M

Data Rate=15Gb/day

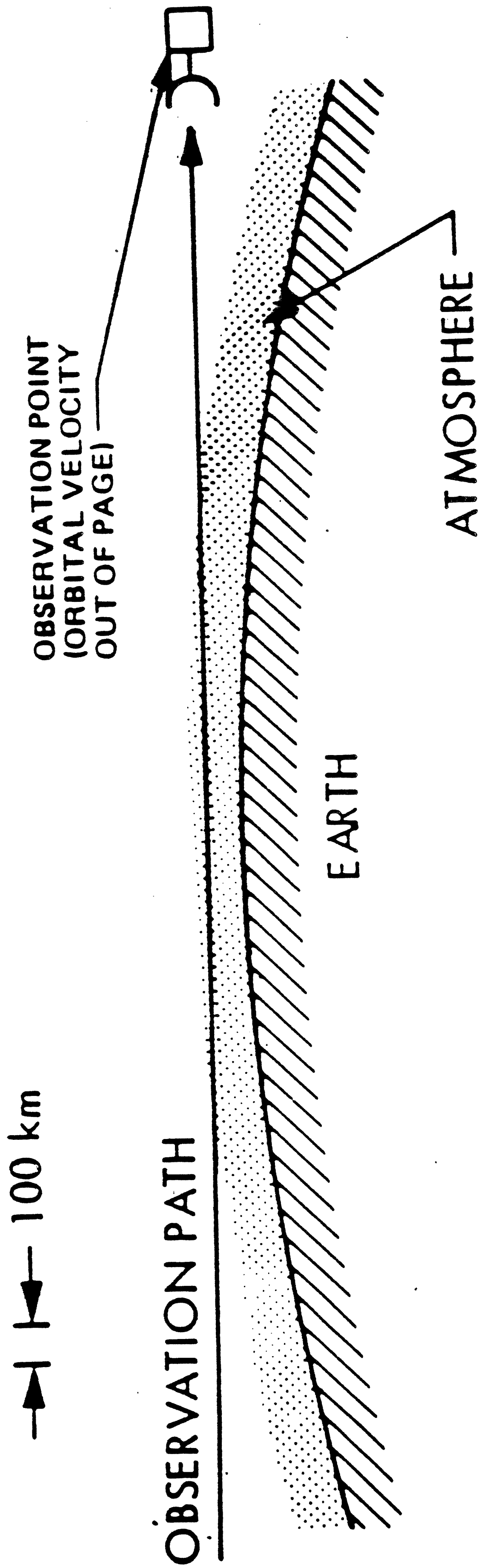
Optics: Off-axis Cass. Eff. f/D=3.75
Ellipsoidal Reflector 1.6x.8m 2.5um RMS

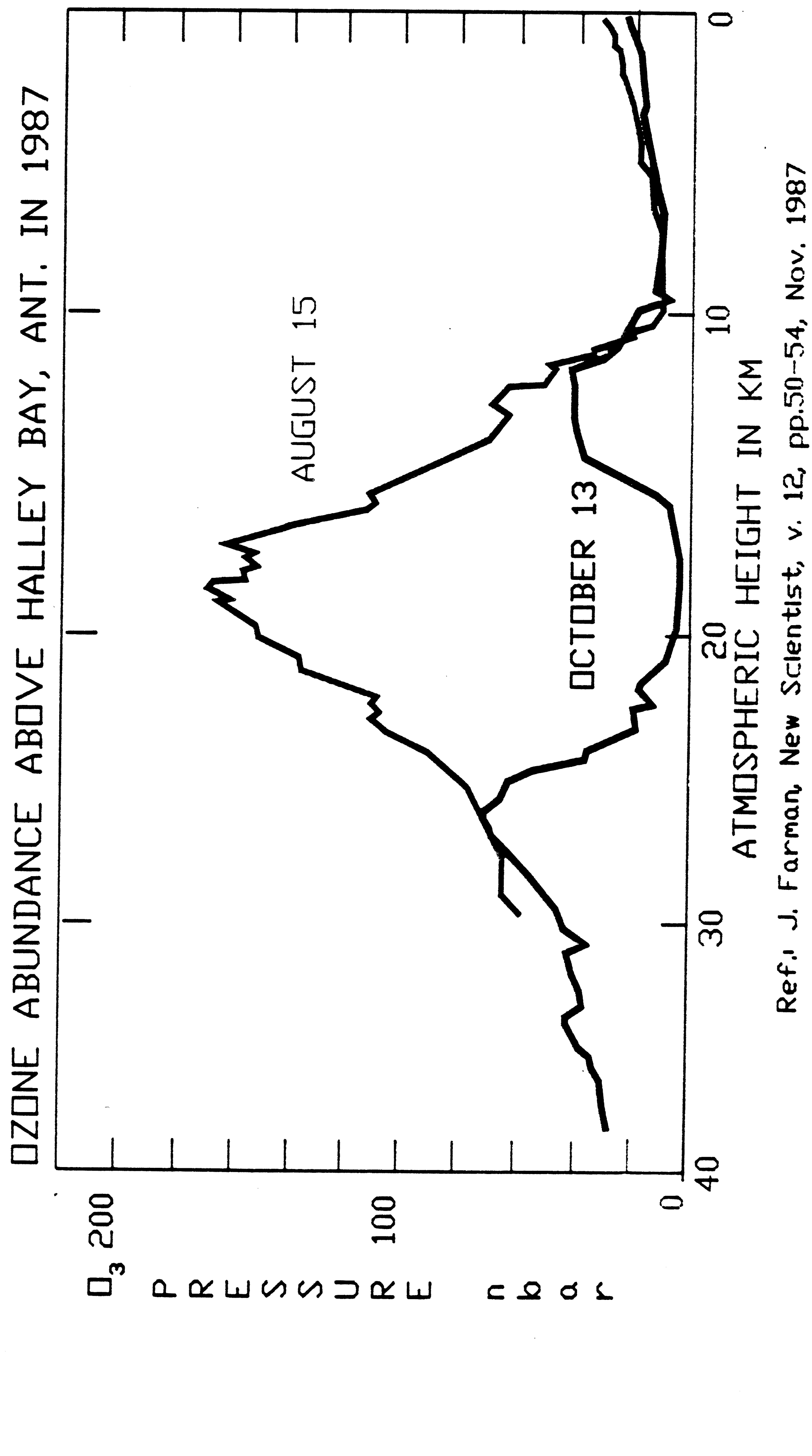
Spectra: 48/scan, 0.64 sec int. time
Vertical Scan Rate=42 sec
Ver. FOV=1.5 arcmin=1.2Km @640GHz

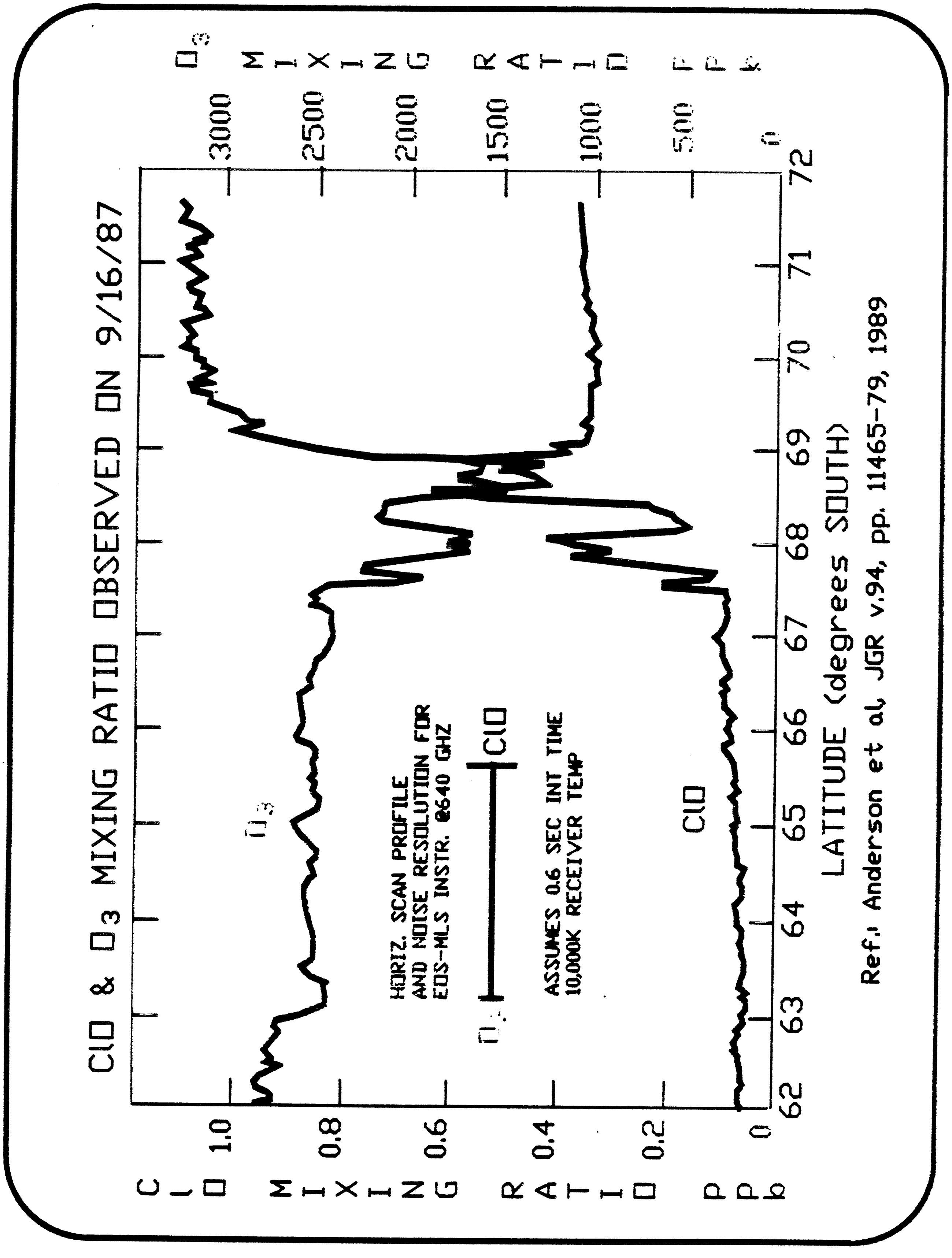
Hor. FOV=2.5 deg along orbit

Front End Radiometers: 640 (2)
540 (2)
440 (2)
220 (1)
63 (1)

LIMB SOUNDING GEOMETRY

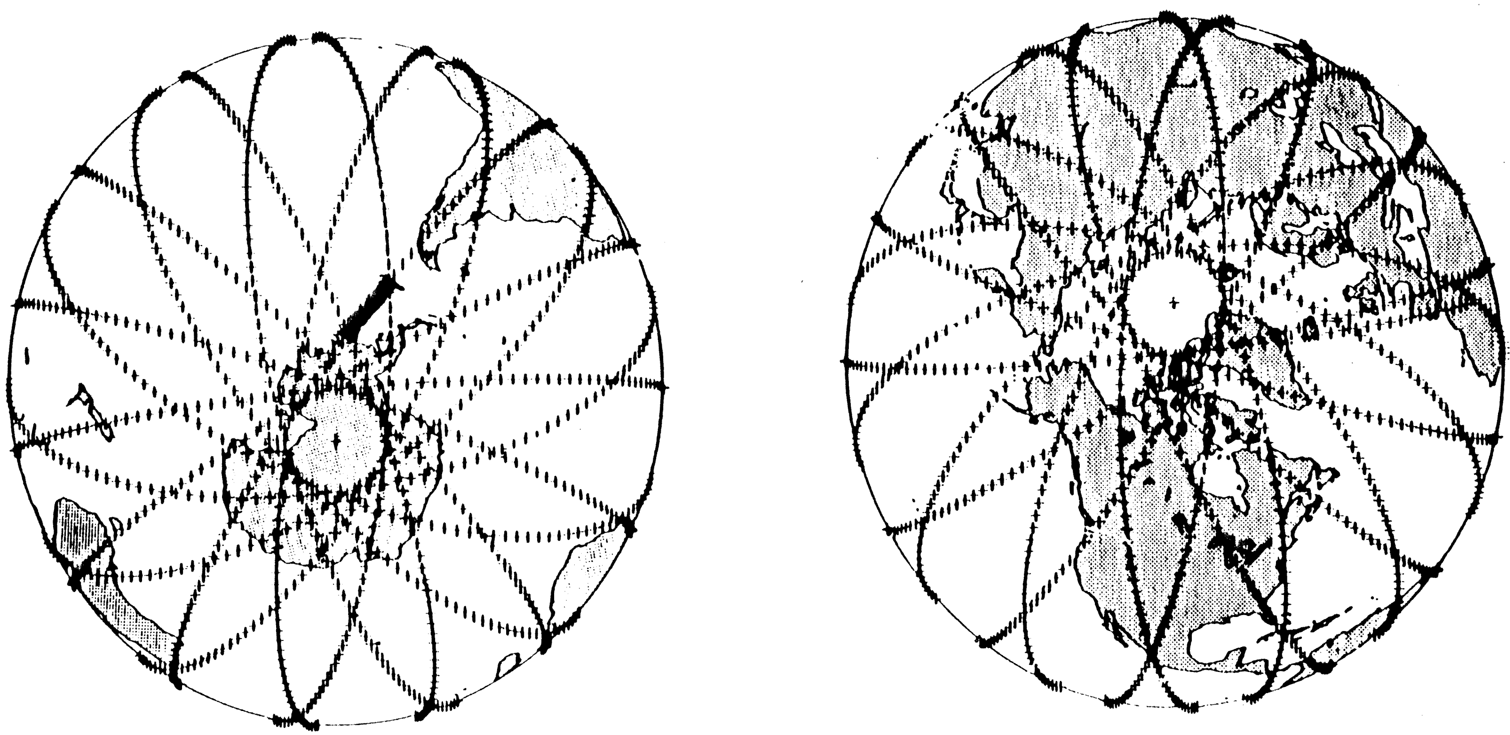



OZONE ABUNDANCE ABOVE HALLEY BAY, ANT. IN 1987
AUGUST 15
OCTOBER 13
ATMOSPHERIC HEIGHT IN KM
O3 PRESSURE nbar
200
100
0
40
30
20
10
0
Ref.: J. Farman, New Scientist, v. 12, pp.50-54, Nov. 1987


ClO & O3 MIXING RATIO OBSERVED ON 9/16/87
ClO MIXING RATIO ppb
1.0
0.8
0.6
0.4
0.2
0
O3 MIXING RATIO ppb
3000
2500
2000
1500
1000
500
0
62
63
64
65
66
67
68
69
70
71
72
LATITUDE (degrees SOUTH)
O3
ClO
HORIZ. SCAN PROFILE
AND NOISE RESOLUTION FOR
EOS-MLS INSTR. @640 GHZ
ASSUMES 0.6 SEC INT TIME
10,000K RECEIVER TEMP
Ref.: Anderson et al, JGR v.94, pp. 11465-79, 1989

Eos MLS Measurement Capability
HORIZONTAL COVERAGE

- Figure shows one day's coverage
  - Each cross, except at pole, is independent vertical profile measurement



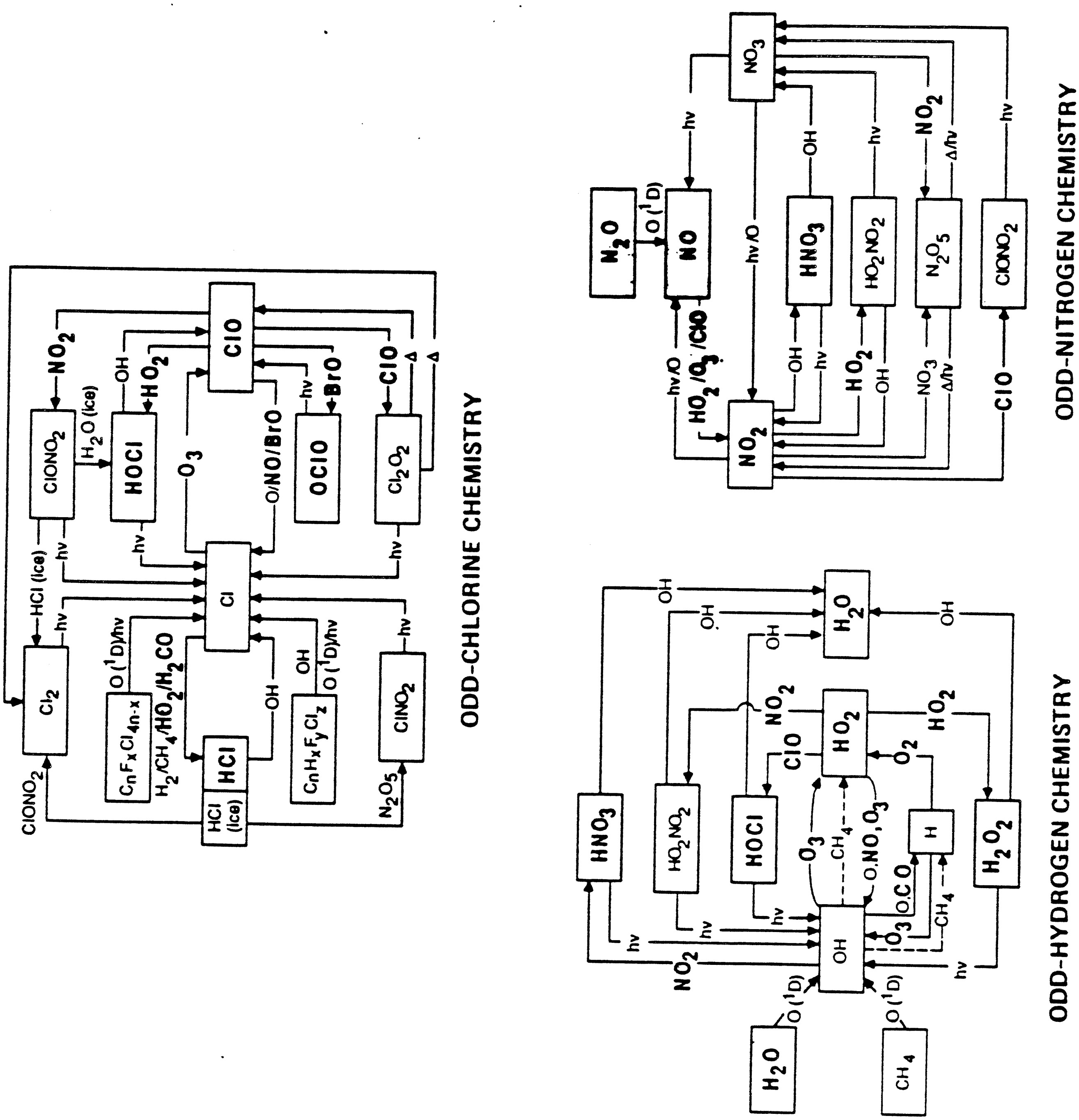
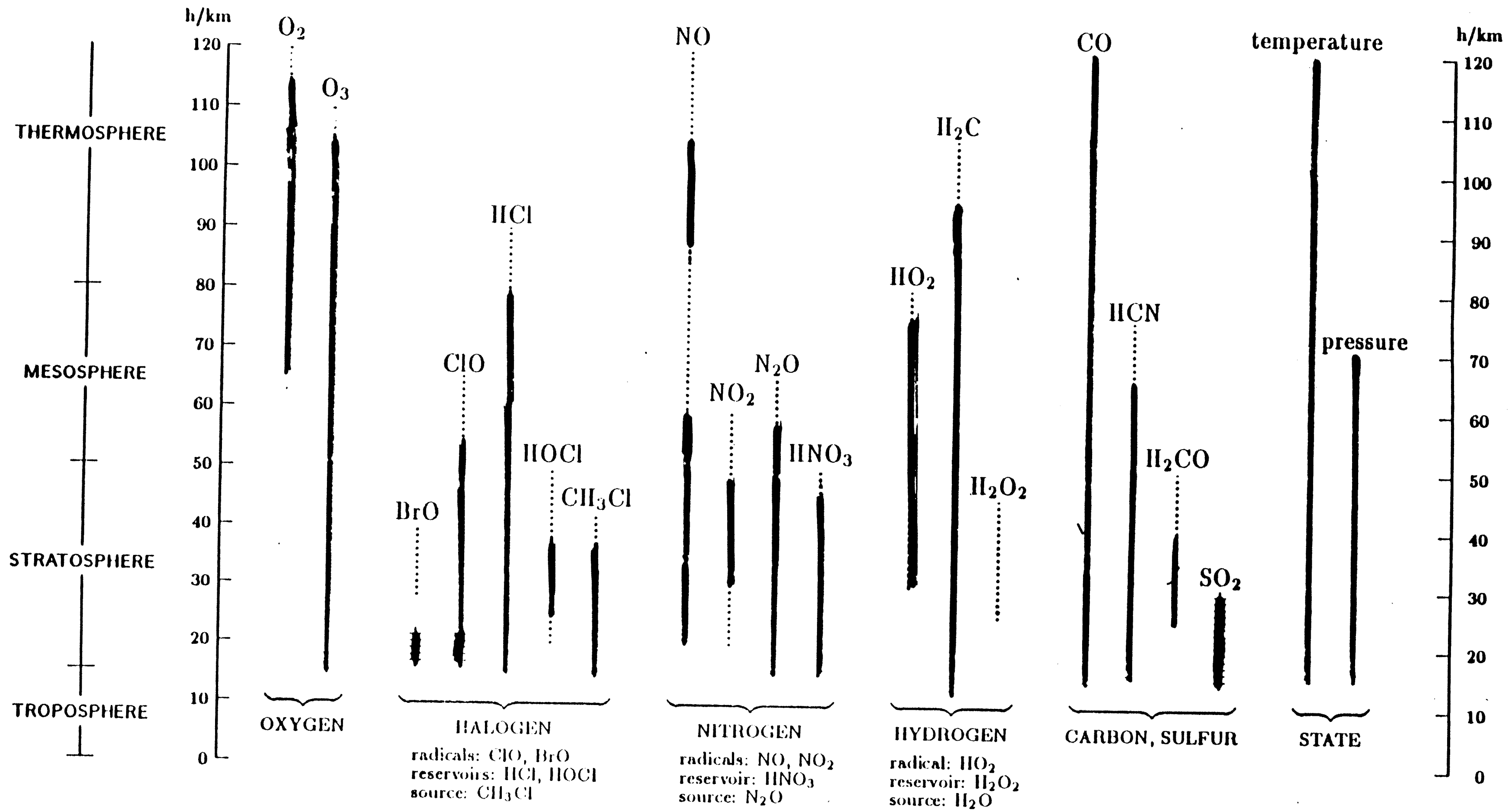


Figure 2. Stratospheric ozone chemistry schematics. MLS measurements in larger type.

Eos MLS: Primary Measurement Objectives



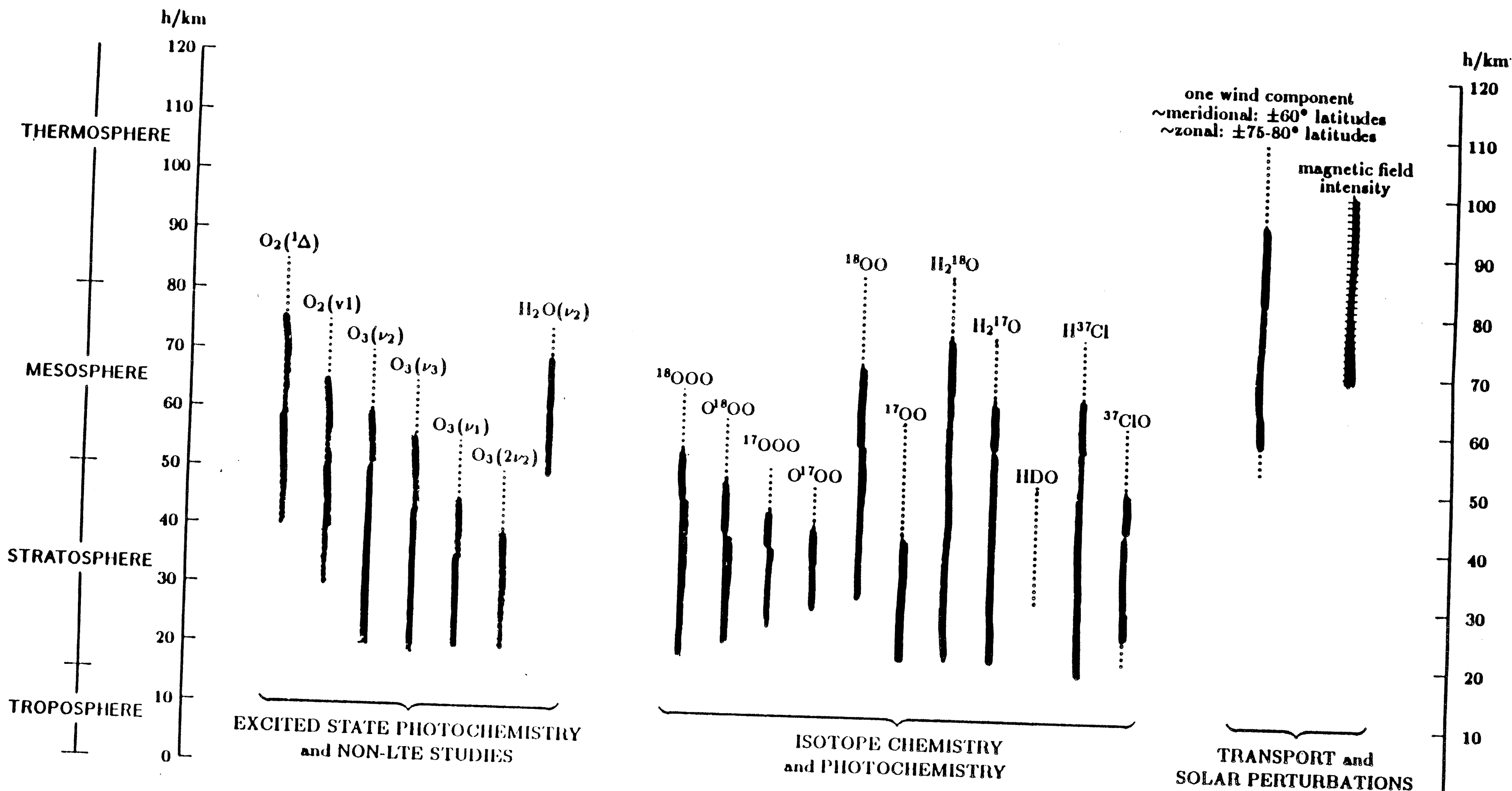
⇒ Individual profiles every 2.5° along great circle of suborbital path

⇒ Daily zonal means (separate day and night); ±80° latitude with 2.5° latitude resolution

⇒ Monthly zonal means (separate day and night); ±80° latitude with 2.5° latitude resolution

⇒ Heterogeneous chemistry enhancements for ClO and BrO; volcanic enhancements for SO_2

Eos MLS: Additional Measurement Objectives



⇒ Individual profiles every 2.5° along great circle of suborbital path

⇒ Daily zonal means (separate day and night); ±80° latitude with 2.5° latitude resolution

⇒ Monthly zonal means (separate day and night); ±80° latitude with 2.5° latitude resolution

⇒ During solar storms (magnetic variations identify areas of solar interaction where resulting chemical perturbations will be studied)

COLLABORATORS ON EOS-MLS RECEIVERS

JPL: P.H. SIEGEL, I. MEHDI, R.J. DENGLER, J. OSWALD
ALL ASPECTS

RAL: B. MADDISON, B. ELLISON, D. MATHESON, M. OLDFIELD
440 & 63 GHZ RADIOMETERS

UVA: T. CROWE, W. BISHOP
SCHOTTKY BARRIER MIXER & MULTIPLIER DIODES

MARTIN MARIETTA: S. WEINREB
BROAD BAND AMPLIFIERS & INTEGRATED MIXERS

UNIV. OF MASS.: N. ERICKSON
HIGH POWER FREQUENCY MULTIPLIERS

ADDITIONAL UNCOMMITTED COLLABORATORS

JPL: J. BAUTISTA AMPLIFIERS
B.A. WILSON PLANAR SCHOTTKY DIODES

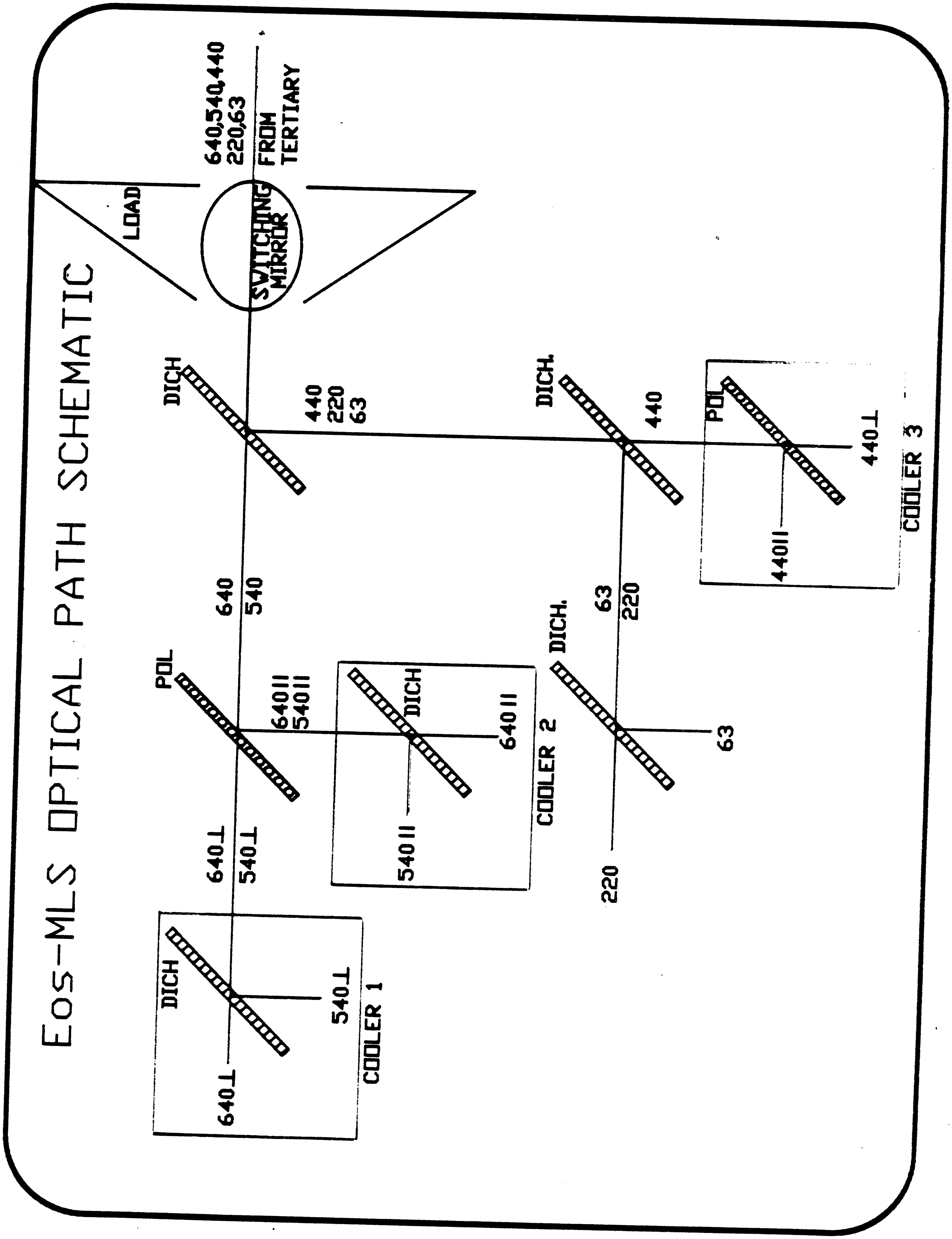
NRAO: M. POSPIESZALSKI
AMPLIFIERS

UMICH: J. EAST
SOLID STATE DEVICES: MIXER/MULTIPLIER/OSCILLATOR DIODES

EOS-MLS HETERODYNE INSTRUMENT DEPLOYMENT

RADIOMETER FREQUENCY PHYS. TEMP	MIXER TYPE NOISE(SSB) LOSS(SSB)	LOCAL OSC. FREQ(GHz) MULTIPLE GUNN(GHz)	IF AMP BAND(GHz)	TIF(K)	TRCVR (SSB)
640 GHz 90K	SHP 5000K 11.5dB	642.85/2 4X 80.356	5.0-10.0 14.0-21.5	40 100	5600 6400
540 GHz 90K	SHP 5000K 11.0dB	535.69/2 4X 66.96	2.0-4.5 6.0-12.0 15.0-22.0	30 50 100	5400 5700 6300
440 GHz 90K	SHP 4500K 10.0dB	442.99/2 3X 73.83	3.0-5.5 7.5-12.0 15.0-21.5	35 50 100	4900 5000 5500
220 GHz AMBIENT	SHP 2000K 8.0dB	216.29/2 1X 108.15	9.5-18.5	180	3100
63 GHz AMBIENT	BAL.MXR 1000K	63.283	.09-.54	50	1200

BACKEND: 32 ACOUSTO-OPTIC SPECTROMETERS: BANDWIDTH=1 GHZ, RES.=1 MHZ
14 DIGITAL AUTOCORRELATORS BANDWIDTH=4 MHZ, RES.=100 KHZ


EOS-MLS OPTICAL PATH SCHEMATIC
LOAD
SWITCHING MIRROR
640,540,440
220,63
FROM TERTIARY
DICH
440
220
63
DICH.
440
POL
440⊥
440∥
COOLER 3
640
540
POL
640∥
540∥
DICH
640∥
540∥
COOLER 2
DICH.
63
220
63
220
640⊥
540⊥
DICH
540⊥
640⊥
COOLER 1

Challenges for Eos-MLS Submillimeter-Wave Radiometry

1. Elimination of the whisker-contacted diode in both the mixer and LO source to improve reliability & ease fabrication

2. Design of a state-of-the-art coolable broadband fixed tuned subharmonically pumped mixer mount using planar diodes to simplify LO generation & injection

3. Design of a high power fix tuned waveguide multiplier using a series array of planar diodes to produce 5-10mW of power at 320 GHz

4. Design of multi-octave bandwidth low noise coolable HEMT amplifiers which can be matched to the SHP mixers over the full IF band

Eos-MLS RADIOMETER PLANS & PROGRESS I.

1. MIXER DEVELOPMENT

- SHP MIXER MOUNT DESIGNED, MODELLED & CHARACTERIZED AT 8 GHZ
- 200 GHZ BLOCKS COMPLETED. MEASUREMENTS TO BEGIN 3/91
- 640 GHZ MOUNT IN CONSTRUCTION

2. MIXER ANALYSIS

- OBTAIN A BETTER UNDERSTANDING OF MIXER PERFORMANCE AT CRYOGENIC TEMPERATURES THROUGH IMPROVED DIODE EQUIV. CIRCUIT
- PERFORM TWO DIODE MIXER ANALYSIS USING MEASURED EMBEDDING IMPEDANCES AND IMPROVED DIODE EQUIV. CIRCUIT
- COMPARE SINGLE & TWO-DIODE SHP MIXER PERFORMANCE

3. PLANAR DIODE DEVELOPMENT

- EXPLORE PLANARIZATION & SUBSTRATE REMOVAL TECHNIQUES ON UVA AIR BRIDGE DIODES TO REDUCE PARASITICS DECREASE MICROSTRIP LOSS & INCREASE MICROSTRIP BANDWIDTH
- 'LIFT-OFF' & 'ETCH BACK' TECHNIQUES TO REPLACE GaAs SUBSTARTE WITH QUARTZ BOTH SUCCESSFUL WITH INDIVIDUAL DEVICES. INTEG. WITH REMAINING MIXER CIRCUITRY EXPECTED 6/91
- EFFECT OF COMPOSITE GaAs/QUARTZ SUBSTRATE ON MIXER FILTER STRUCTURES STUDIED & CHARACTERIZED
- NEW DIODE STRUCTURES & MATERIALS BEING STUDIED AT UMICH & UVA
- FULLY INTEGRATED MIXER BEING DEVELOPED AT MARTIN MARIETTA

Eos-MLS RADIOMETER PLANS & PROGRESS II.

4. HIGH POWER PLANAR MULTIPLIER DEVELOPMENT

UVA PLANAR VARACTOR DIODE DEVELOPMENT UNDERWAY
MULTI-DIODE MULTIPLIER BLOCK DESIGN TO BEGIN 6/91 AT UMASS

5. AMPLIFIER DEVELOPMENT

BROADBAND INTEGRATED AMP UNDER DEVELOPMENT AT MARTIN MARIETTA
OCTAVE BAND HEMT AMPLIFIERS UNDER DEVELOPMENT AT JPL/NRAO
UNDER SEPARATE IN HOUSE PROGRAMS

6. RADIATIONAL COOLER DEVELOPMENT

80K RADIATIONAL COOLERS BEING DEVELOPED AT SBRC
JPL COOLER DEVELOPMENT EFFORT TO BEGIN IN 92

MIXER PERFORMANCE VS. TYPE AND FREQUENCY

	Whisker Contact							Planar				
freq GHz	FM		HM		SHPM			FM		SHPM		
	Tm	Ldb	Tm	Ldb	Tm	Ldb	P_{LO}	Tm	Ldb	Tm	Ldb	P_{LO}
100	450[1]	6.0			400[5]	7.4	6	560[9] 750[10]	5.9 6.5	1750[10]	9.5	
200	800[2]	6.6			1800[6] 3450[7] 2400[8]	8 Trec 10.5	10 15 6.5			2750[11] 3000[12]	Trec	10
650	5200[3]	12.0	4300[4]	13								

All results are for waveguide mounts at T=300K and f_{IF}<2 GHz
Tm and Ldb are SSB noise and loss, P is required LO in mW

References: (1) Cong,Kerr,Mattauch, MTT-27, Mar. 1979, pp.245-8
(2) Archer, MTT-30, Aug. 1982, pp.1247-52
(3) Erickson, private comm. April 1990
(4) Erickson, 1st Int. Conf. on Space THz Tech, U.Mich, Mar.5,1990
(5) Carlson,Schneider,McMaster, MTT-26, Oct. 1978, p.712
(6) Carlson,Schneider, Int.Conf. on IR&MM Waves, 1979, pp.82-3
(7) Galin, IR&MM Waves, v.8, 1987, p.123
(8) Mann,Matheson,Jones, IR&MM Waves, v.10, 1989, pp.1043-49
(9) Garfield, private comm. UVa, April 1990
(10) Archer, MTT-38, Jan 1990, pp.15-22
(11) Ostdiek,Crowe,Galin, 15th Int.Conf.IR&MM Waves, Dec. 1990
(12) B. Maddison, B. Ellison, private comm., Jan 1991.