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High Data Rate Instrument Study

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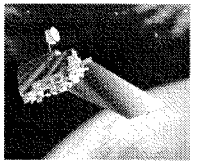

High Data Rate Telecommunications Trade Study: Data Return Options and Link Architecture

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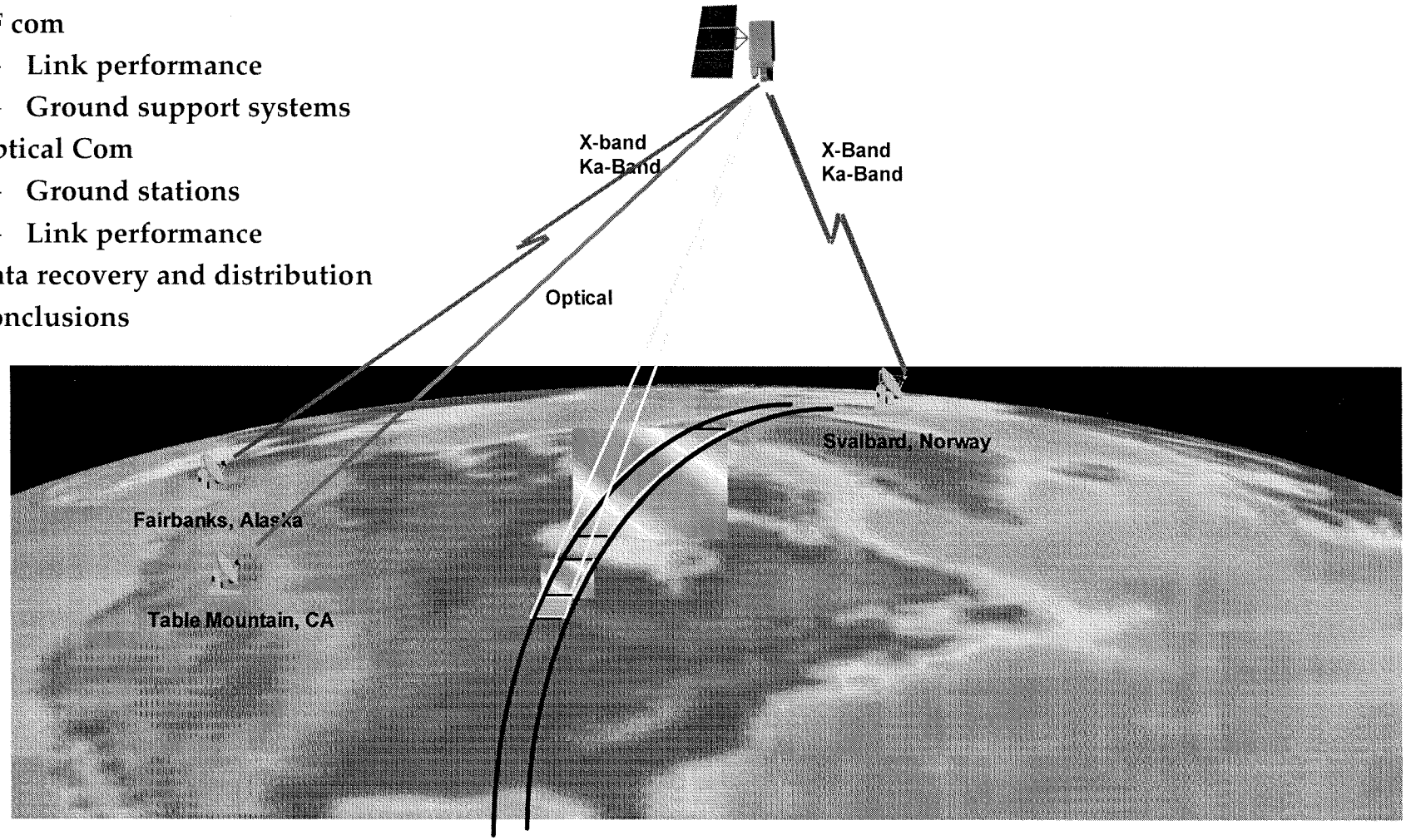
Outline of Talk

- Study Objective
- Data return options
- RF com
  - Link performance
  - Ground support systems
- Optical Com
  - Ground stations
  - Link performance
- Data recovery and distribution
- Conclusions

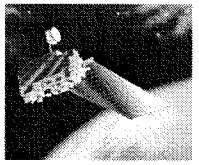


Study Objective

To explore onboard data management and high data rate telecommunications strategies to return extremely high data volumes from space, by considering:

- **On-Board Data Management**
  - Intelligent Data Extraction
  - On-Board Storage and Processing
  - Image Compression
- **Telecommunications**
  - X & Ka -Band
  - Optical
  - Ground Data Distribution

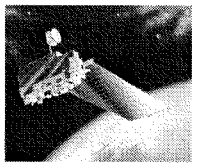
Spacecraft Instruments



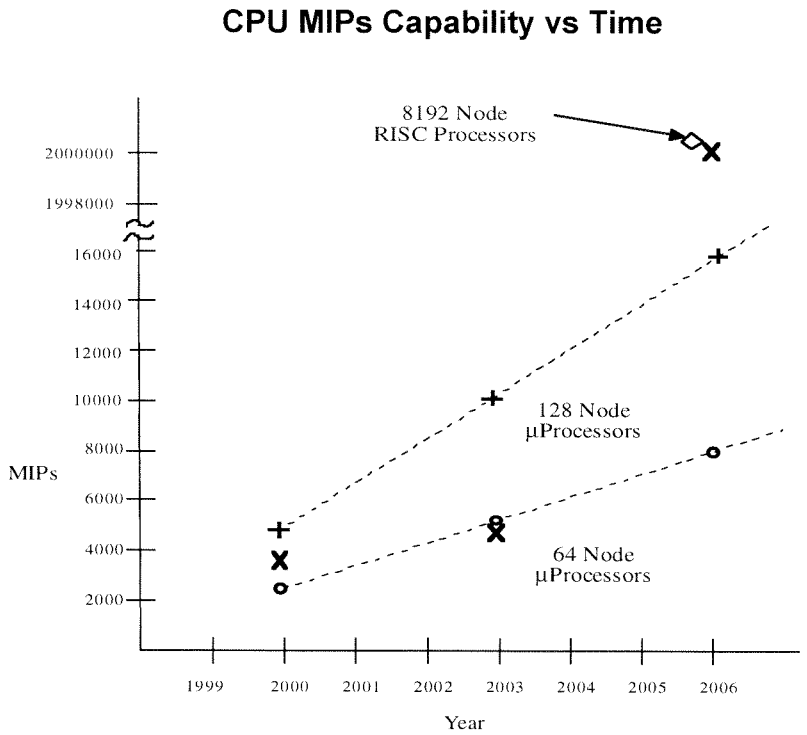
- **Advanced science instruments will require improved data processing and higher telecommunications data rates**

Instrument/Year	**2000**	**2003**	**2006**
Hyperspectral	1.6 Gbps	3.2 Gbps	40.3 Gbps
SRTM/LightSAR	180 Mbps	1.3 Gbps	4.8 Gbps
LIDAR	5 Mbps	5 Mbps	5 Mbps
Study Link Rates	**0.1 Gbps**	**1 Gbps**	**10 Gbps**

On Board Data Processing



- 5000 MIP, 128 node processor array is needed to meet the requirements of the 2000 mission
  - Hardware is about 1 foot cube and uses considerable power.
- An advanced technology 4500 MIP, 64 node processor array would meet the requirement for the 2003 mission
- It is questionable if a reasonable number (<200 node) of RISC processor could meet the needs of the 2006 mission requirements.



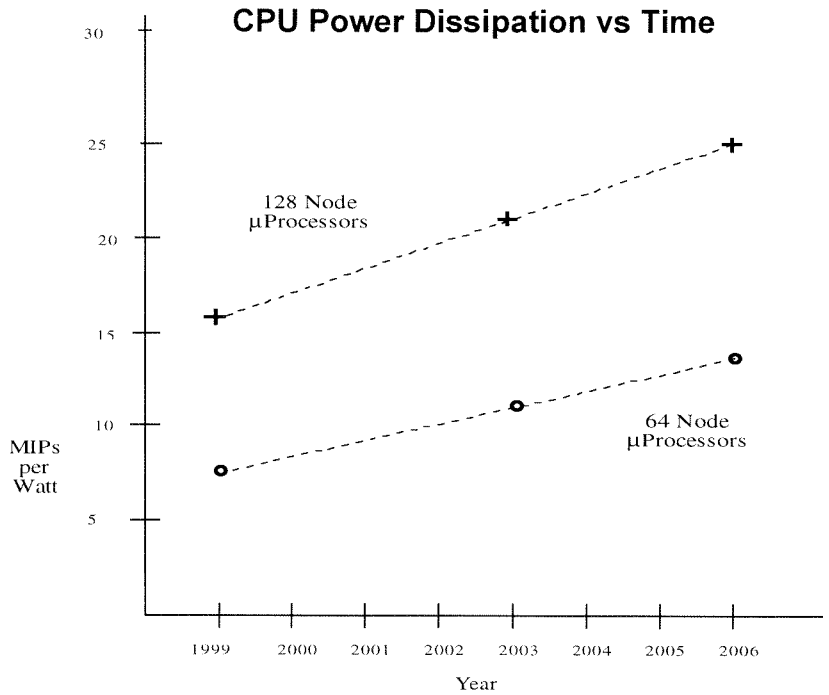
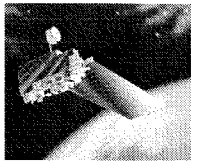
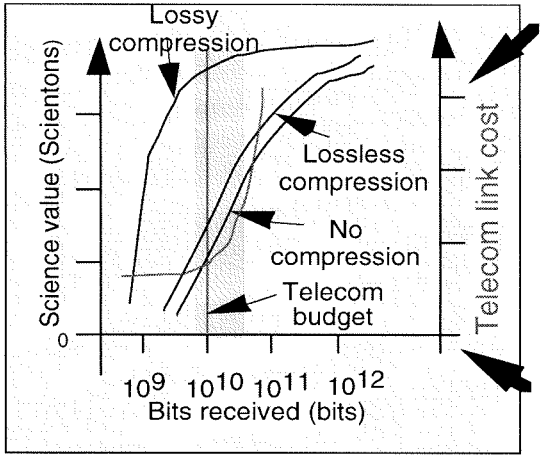


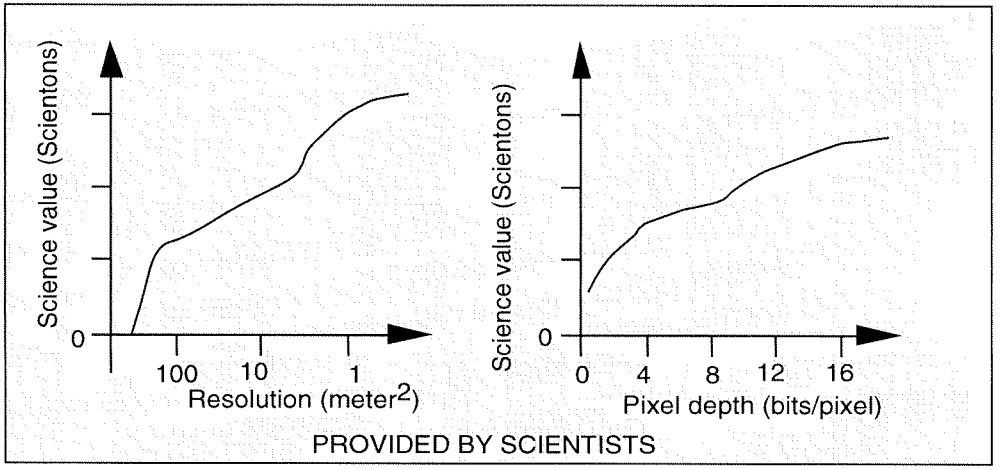
Image Compression

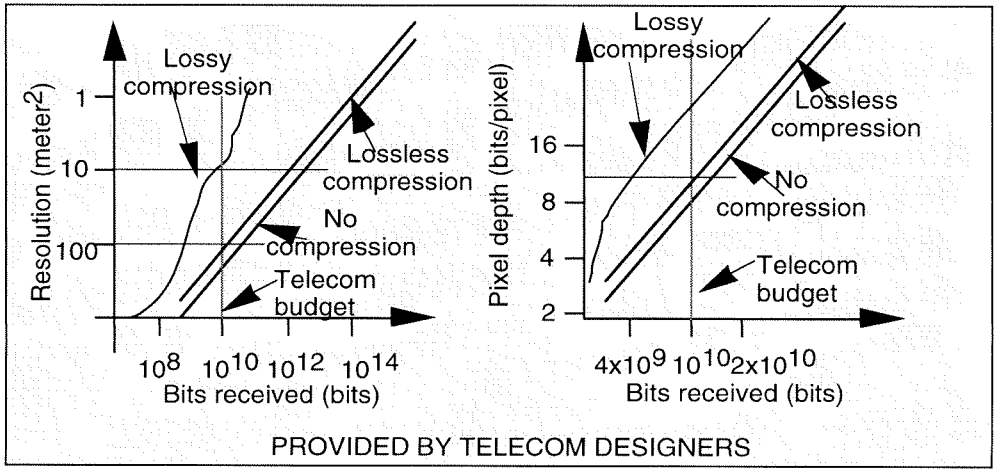


Rational for choosing Data Compression & Possible Compression Techniques:

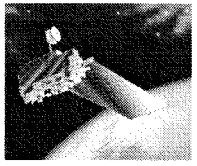
- **Compression by Refusing to Collect More Data**
- **Lossless Compression**
- **Lossy Compression**



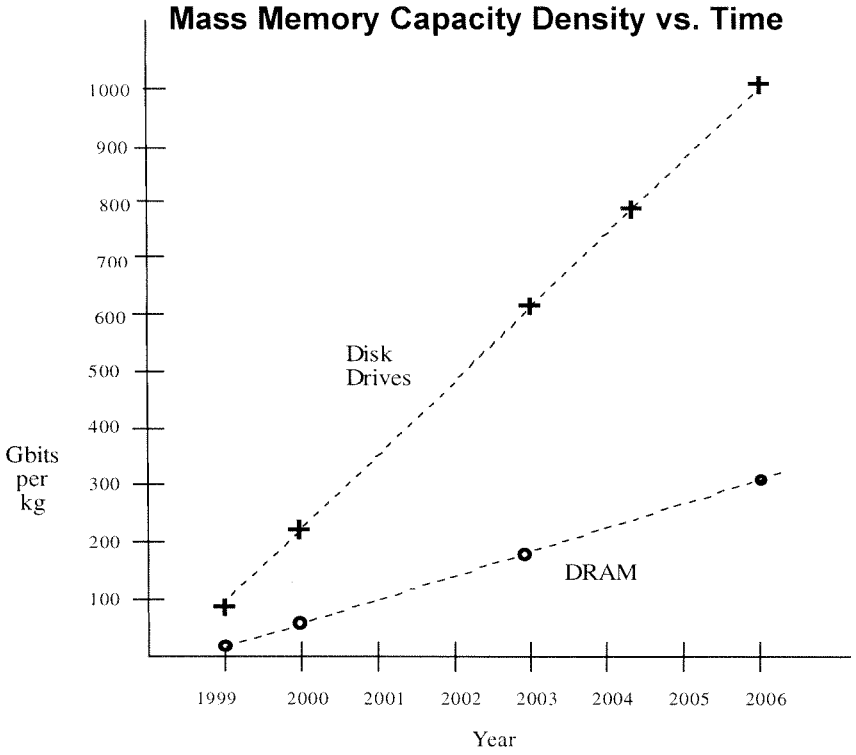


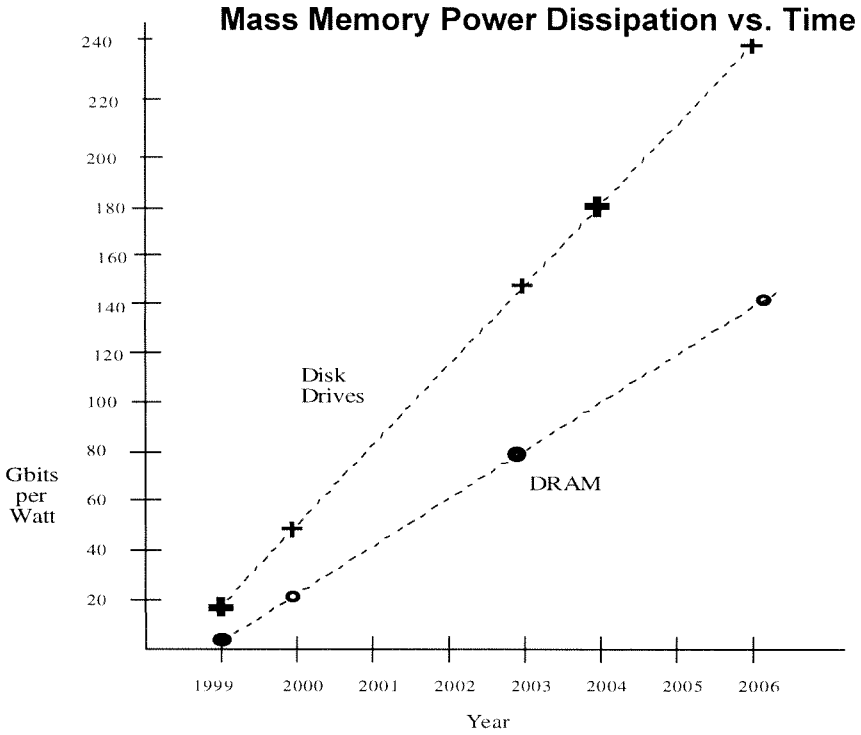


Increased On-Board Data Storage



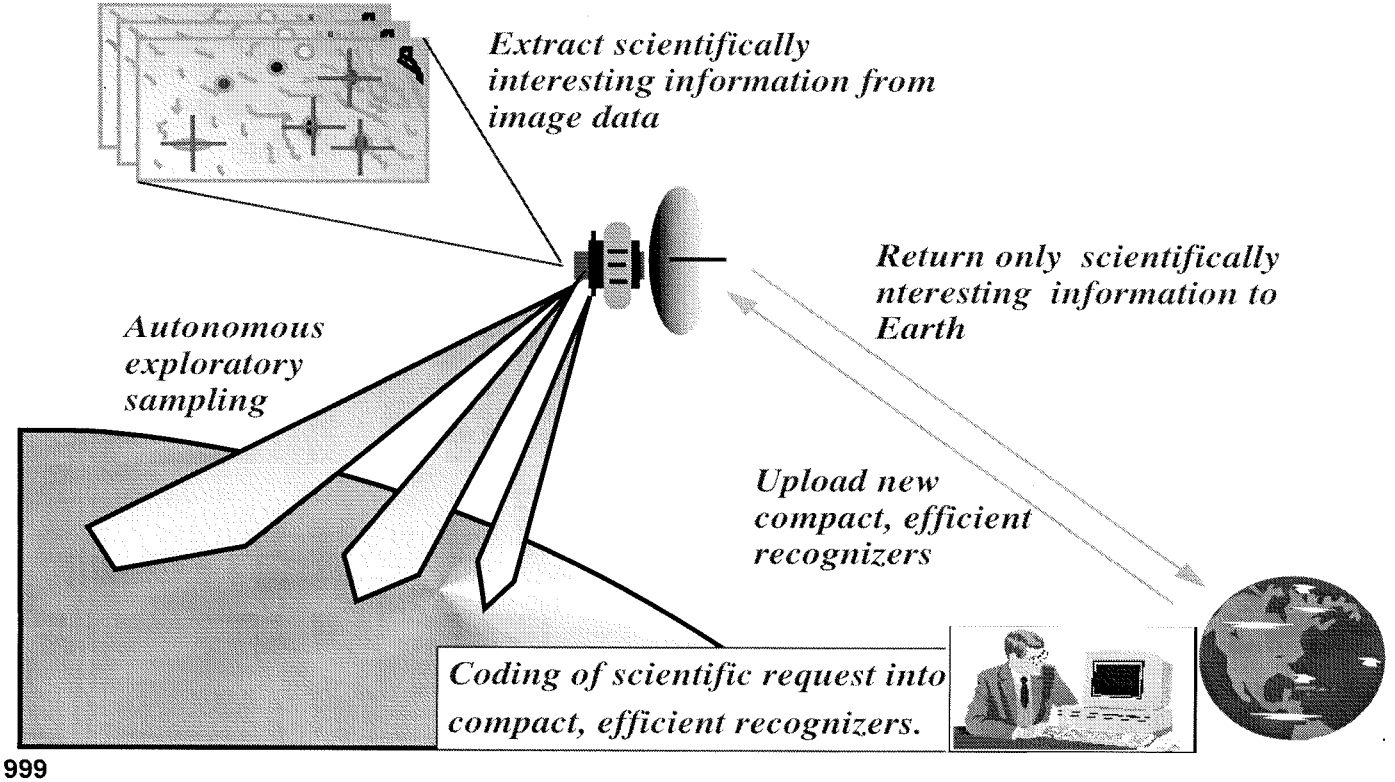
- Commercial data indicates memory density per kg is greater for disk drive technology than for SSRs implemented with FLASH or DRAM memory.
- Anticipate feature sizes for DRAM and MRAM devices to decrease with technological advances
  - Very high density, low mass and low power SSR may be available to meet 2003 target



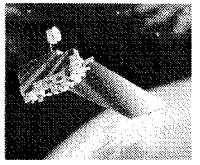


Intelligent Data Extraction

- Science Driven on-Board Feature Extraction Procedure automates Loop between science request and data delivery
  - Can reduce required downlink bandwidth requirement by two orders of magnitude
- Scientist indicates data types of interest
- Selection is automatically extracted from images and fed through machine learning software On-board computational process extracts features from image data and downlinks to ground
- **Power and size requirements needed to implement this approach is not clear**
  - **Does not provide means of preserving data for later review**



Telecommunications Technologies Assessment



- **Reviewed telecommunications options to meet telecommunications demands of 0.1 Gbps, 1 Gbps and 10 Gbps downlink data rates**
- **Considered X-Band, Ka-Band and optical communications technologies**
  - 0.1 GHz allocated spectrum bandwidth for Earth orbiting satellites telecommunications, and absence of hardware limits X-band rate to < 1 Gbps.
  - 1 Gbps at Ka-Band achieved by propagating 0.6 Gbps on two downlink frequencies within allocated bandwidth
    - High data rate Ka-Band will require development of high speed receivers
- **No technology nor spectrum limitations on optical, it can support all data rates**

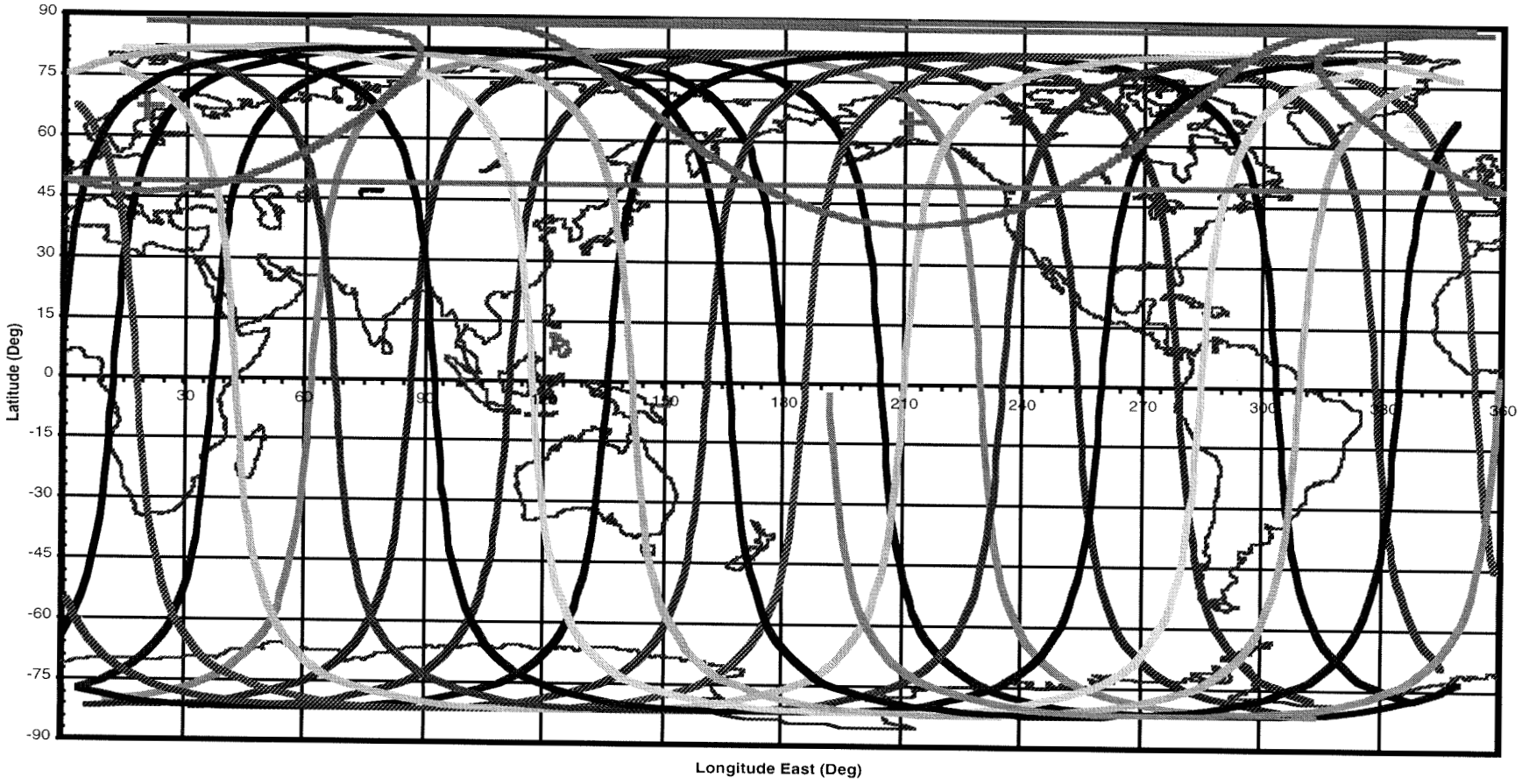
Gbps \ Year	'00	'03	'06
0.1	Opt, X-band, Ka-Band	Opt, X-band, Ka-Band	Opt, X-band, Ka-Band
1.0	Opt	Opt	Opt, Ka-Band
10	Opt	Opt	Opt

RF Ground Station Locations

RF Ground Stations:

Svalbard, Norway and ASF, Alaska

Satellite Ground Track



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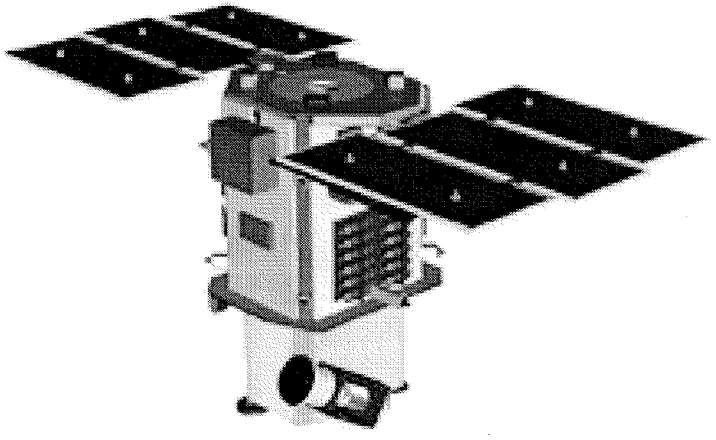
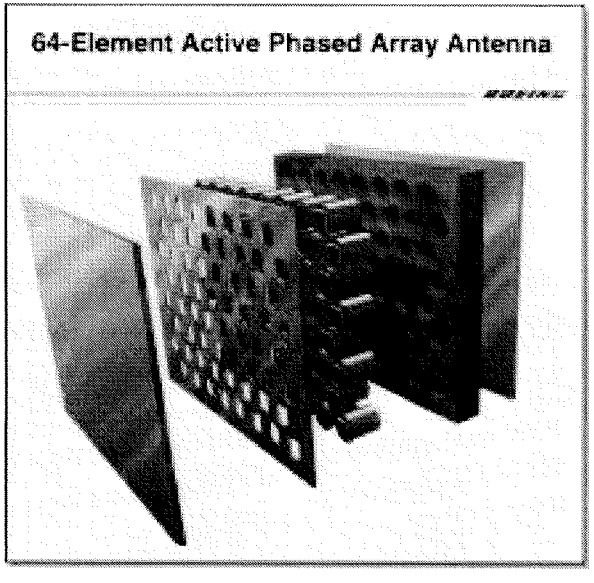
RF Telecommunications Hardware

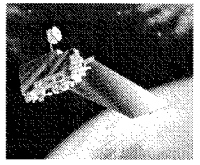




commercial Satellite, transmits up to 320 Mpbs

Element Active Phased Array Antenna, Boeing for GSFC

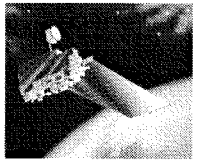
X-Band & Ka-Band Link Budgets



X-Band Link Budget	
Transmit - Receive Range (Kn	700
Link Frequency (MHz)	8450
Rcv Stn. Ant name & Diamete	Name: ASF Diam.: 11.3
Total Link Losses (dB)	4
Data Channel 1::::::::::::::	
Modulation Format	Direct Modulation
Bit Rate (kbps)	300,000
Bit Error Rate	1.00E-06
Coding Used	None
Data Margin (dB)	3
Carrier Margin (dB)	6
S/C Antenna Size (m)	Omni
Full 3 dB Beamwidth (Deg)	128
Transmitted RF Power (W)	70

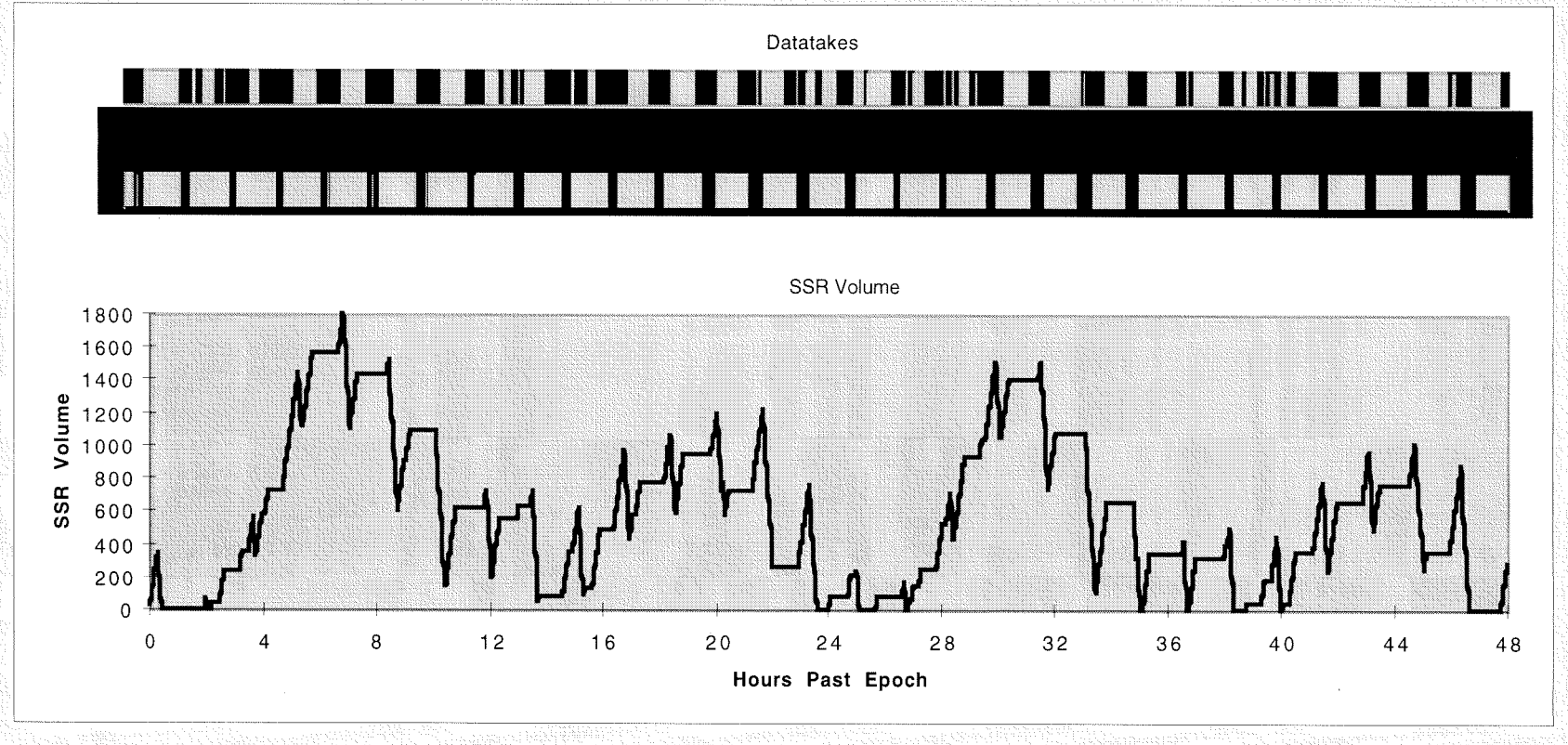
Ka-Band Link Budget	
Transmit - Receive Range (	700
Link Frequency (MHz)	32000
Rcv Stn. Ant name & Diame	Name: ASF Diam.: 11.3
Total Link Losses (dB)	6
Data Channel 1::::::::::::::	
Modulation Format	Direct Modulation
Bit Rate (kbps)	600,000
Bit Error Rate	1.00E-06
Coding Used	None
Data Margin (dB)	3
Carrier Margin (dB)	6
S/C Antenna Size (m)	0.0134
Full 3 dB Beamwidth (Deg)	42
Transmitted RF Power (W)	20

RF Telecommunications Data Flow



SSR data flow over forty-eight hour period for RF downlink at 1 Gbps

1.0 Gb/s D/L, 2 hi-lat sta, 700km alt, 98 deg, All Land Imaged

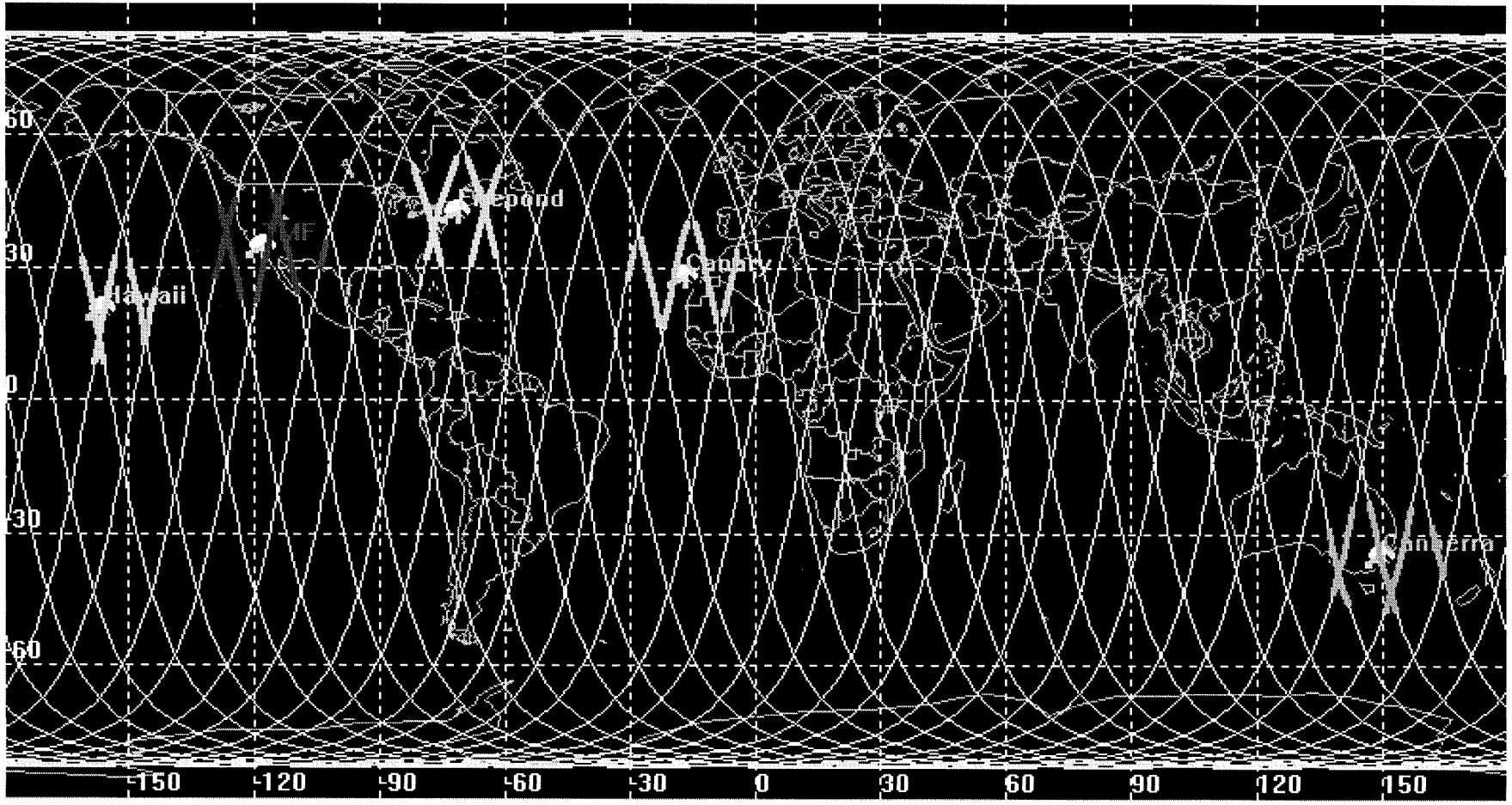


Units	Gbits	SSR Max Volume	2000 Gbits	Data Taken/Second of Observation	0.35 Gbits
		Initial SSR Volume	0 Gbits	Data Downlinked Per Second	1 Gbits

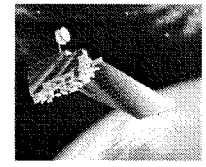
Optical Ground Stations

Optical Comm. Ground Stations:

NASA/JPL TMF, OCTL, Canberra, Aus, AFRL AMOS Maui, HI,
ESA Tenirife, Canary Islands, and MIT Lincoln Labs Firepond



Optical LEO-to-Ground



- Milliwatt level laser transmitters coupled to a small 10 cm telescope supports robust optical communications link
  - Optical transceiver design based on JPL proto-flight optical communications terminal being developed at JPL and 1-m class ground telescopes
- By 2000 technology will support 10 Gbps by wavelength division multiplexing four 2.5 Gbps links

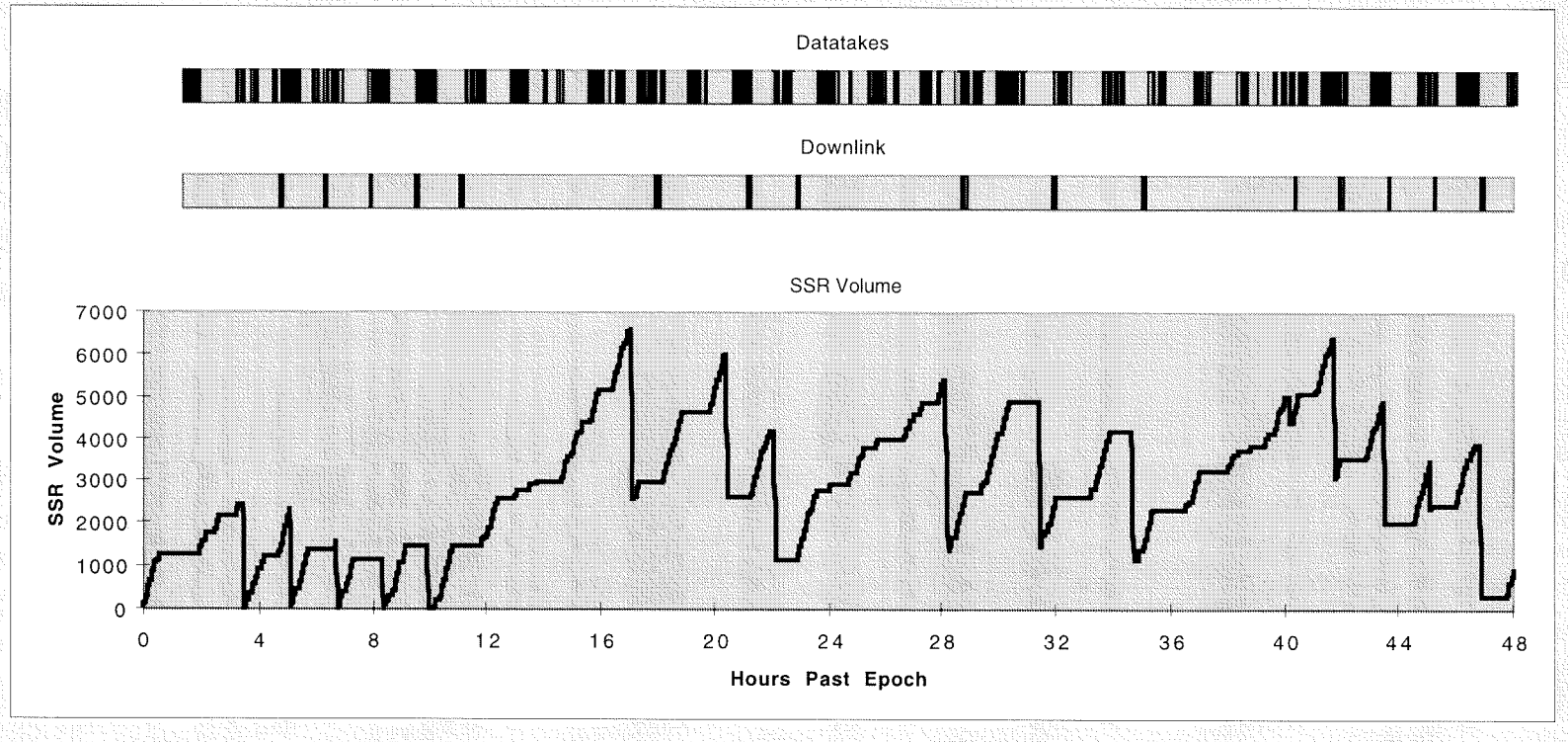
HDR Link (2.5 Gbps)

Link Summary					
Link Range	1.58E+03	km			
Data rate	2.50E+06	kbps	On-Off Keying		
Coded BER	1.00E-08		No Coding		
Transmit power	0.15	W average	300.00 mW (peak)	24.77	dBm
Transmit losses	40.0	% transmission		-3.98	dB
Transmitter gain	27.5	urad beamwidth		104.23	dB
Pointing losses				-0.97	dB
Space loss				-262.17	dB
Atmospheric losses	86.1	% transmission		-0.65	dB
Receiver gain	1.00	m aperture diameter		125.73	dB
Receiver optics losses	32.7	% transmission		-4.86	dB
Received signal	5.06E+04	photons/pulse	16.23 uW (peak)	-17.90	dBm
Background signal level	7.77E-02	photons/slot	24.90 pW		
Required signal level	1.08E+03	photons/pulse	0.35 uW (peak)	-34.61	dBm
Link Margin				**16.71**	**dB**

LEO-Ground Data Flow

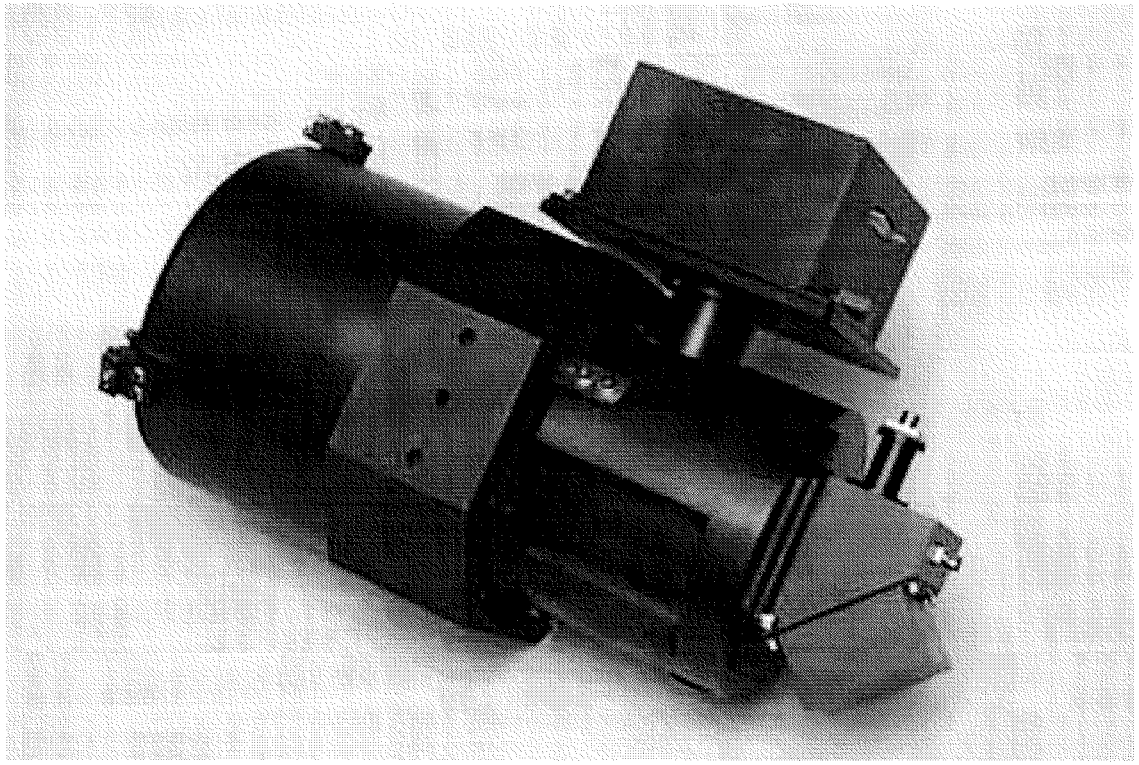
10 Gbps downlink to three stations at CONUS

10 Gb/s D/L, 3 opt sta, 700km alt, 98 deg, All Land Imaged



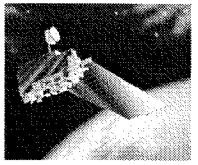
Units	Gbits	SSR Max Volume	7000 Gbits	Data Taken/Second of Observation	0.75 Gbits
		Initial SSR Volume	0 Gbits	Data Downlinked Per Second	10 Gbits

Optical Communications Hardware



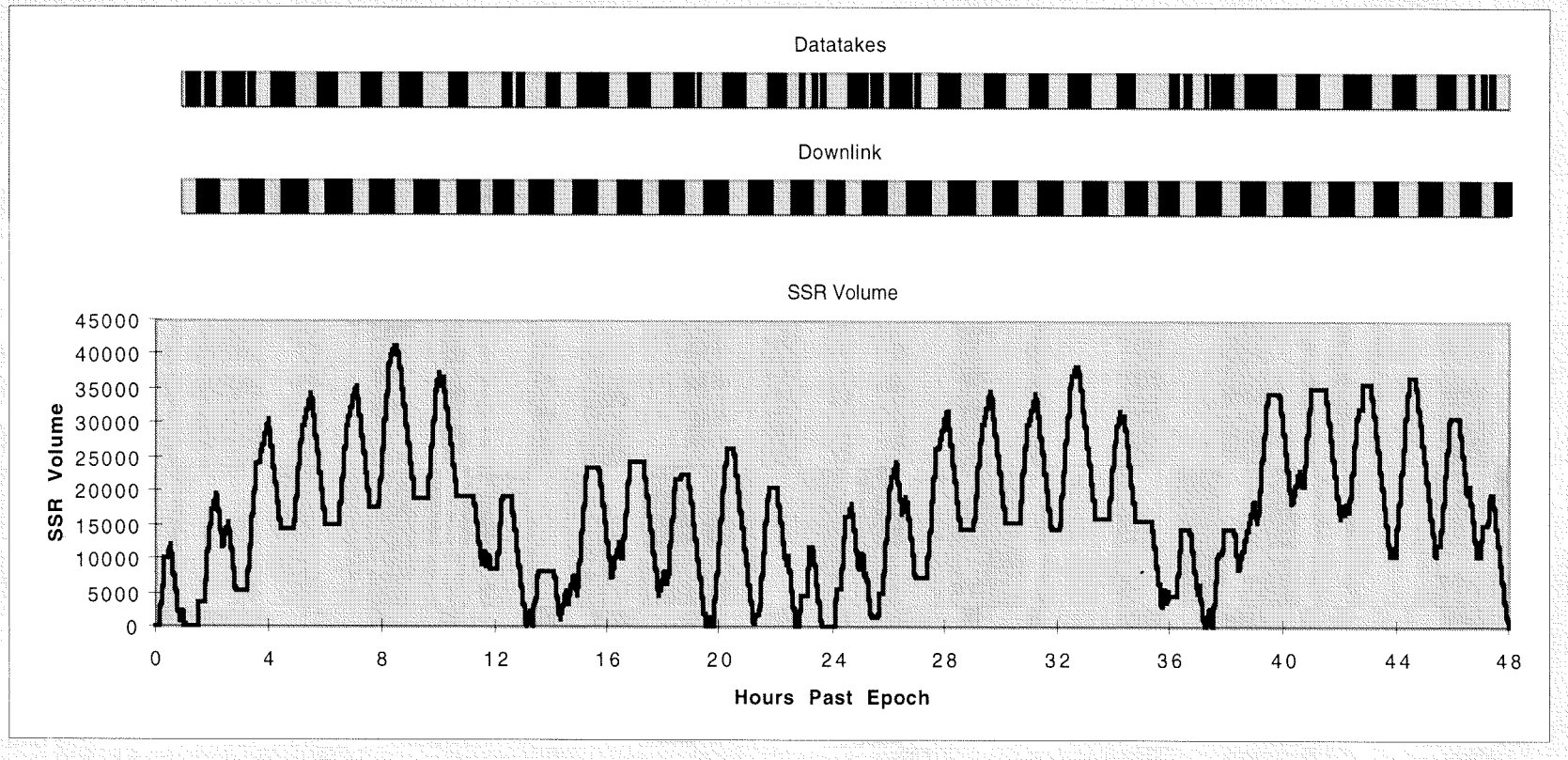
Optical communications Demonstrator

LEO-GEO link



Relay satellite with 10 Gbps crosslink with 10 Gbps downlink will support 15 Gbps operational instrument rates at LEO satellite

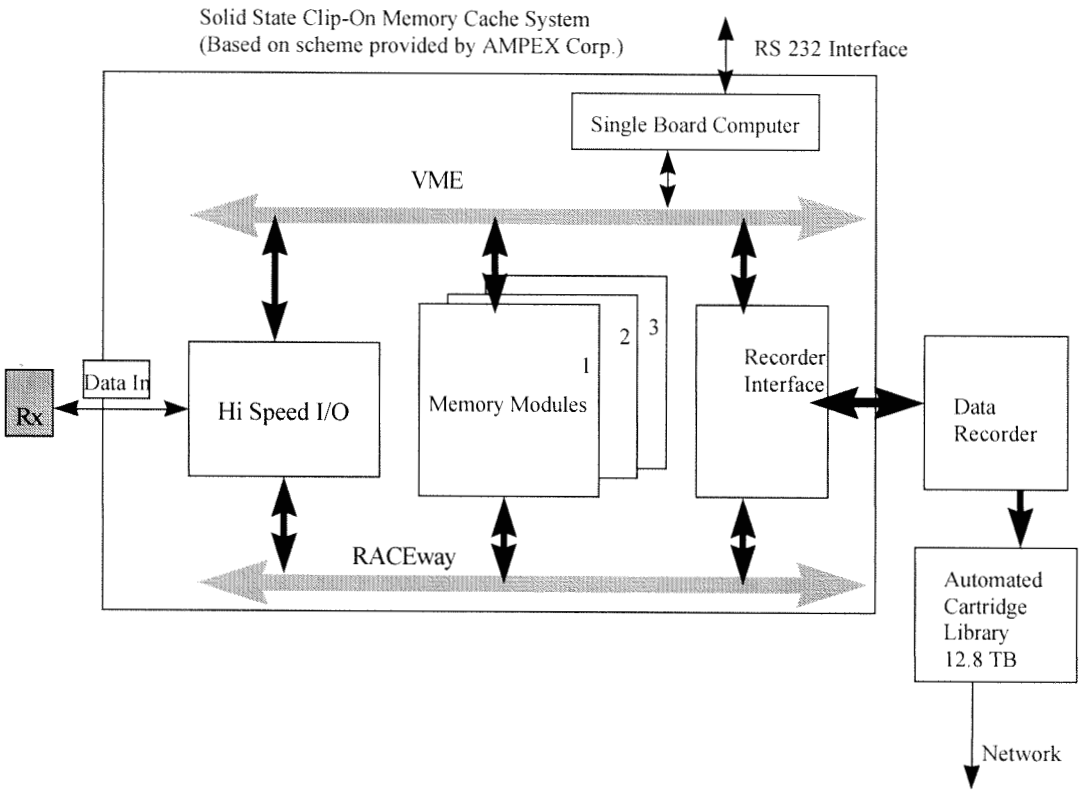
10 Gb/s Crosslink to GEO, 700km alt, 98 deg, All Land Imaged



Units	Gbits	SSR Max Volume	50000 Gbits	Data Taken/Second of Observation	15 Gbits
		Initial SSR Volume	0 Gbits	Data Downlinked Per Second	10 Gbits

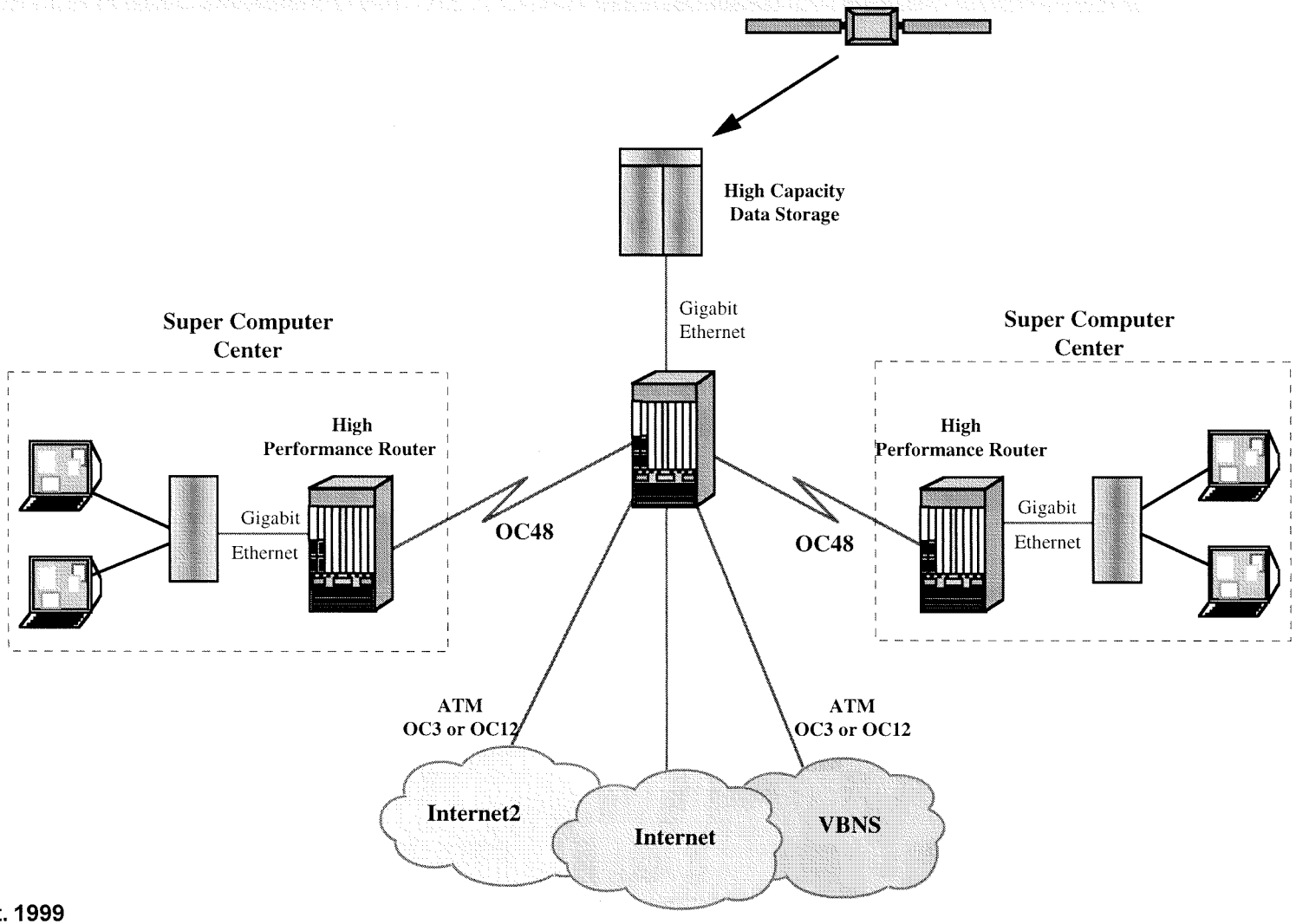
Ground System Data Recovery and Storage

- **The receiver output is stored on 16 Gbyte DRAM memory modules**
  - **Currently, data stored on DRAM via high speed I/O port operating at 1.2 Gbps**
    - Projected growth is to 2.5 Gbps by '00, 5 Gbps by '03, and 10 Gbps by '06
- **DRAM data transfer to magnetic tape is at 0.160 Gbps**
  - **Rates are projected to grow to 0.24 Gbps by '00, 0.64 Gbps between '03 and '06**



Data Delivery

- CONUS stations distribute data via OC-12 connection to Internet
- Other stations store data on tape and ship to PI



Conclusions

- **Both RF and optical will support 0.1 Gbps by year '00 technology cut off**
  - In near term, RF has a clear advantage at 0.1Gbps because of existing infrastructure.
- **Ka-Band and optical will support 1 Gbps**
  - Ka-Band is expected to support data rate by year '06 technology cut off using two frequency multiplexing of 0.6 Gbps links
  - Optical using single laser 1550 nm at wavelength
- **Only optical will support 10 Gbps**
  - Achieved using four color wavelength division multiplexing (4 x 2.5 Gbps)
    - Leverages off developments in fiber optics communications technology
  - **LEO-to-GEO cross link**
    - **Reduces needed number of ground stations for weather diversity**
    - **Allows for rapid offloading of data from LEO satellite**
- **Data volume is downlinked in 2006 using a combined approach**
  - **High data rate telecommunications, on board storage, and intelligent data extraction**