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School on "Exploring the Atmosphere by Remote Sensing Techniques"
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"Electro-Optical Space Instruments for Atmospheric Remote Sensing"

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Please note: These are preliminary notes intended for internal distribution only.

ELECTRO-OPTICAL SPACE INSTRUMENTS FOR ATMOSPHERE REMOTE SENSING

Presented by: D. Labate
Trieste, October 21, 1999

SUMMARY

- Types of electro-optical instruments
- Main application for atmosphere sensing
- What EO instruments measure
- From raw measurement to end use products
- Examples of EO instruments:
    - Global Ozone Monitoring Experiment (GOME)
    - REFIR
    - Cloud Imager

TYPES OF EO INSTRUMENTS

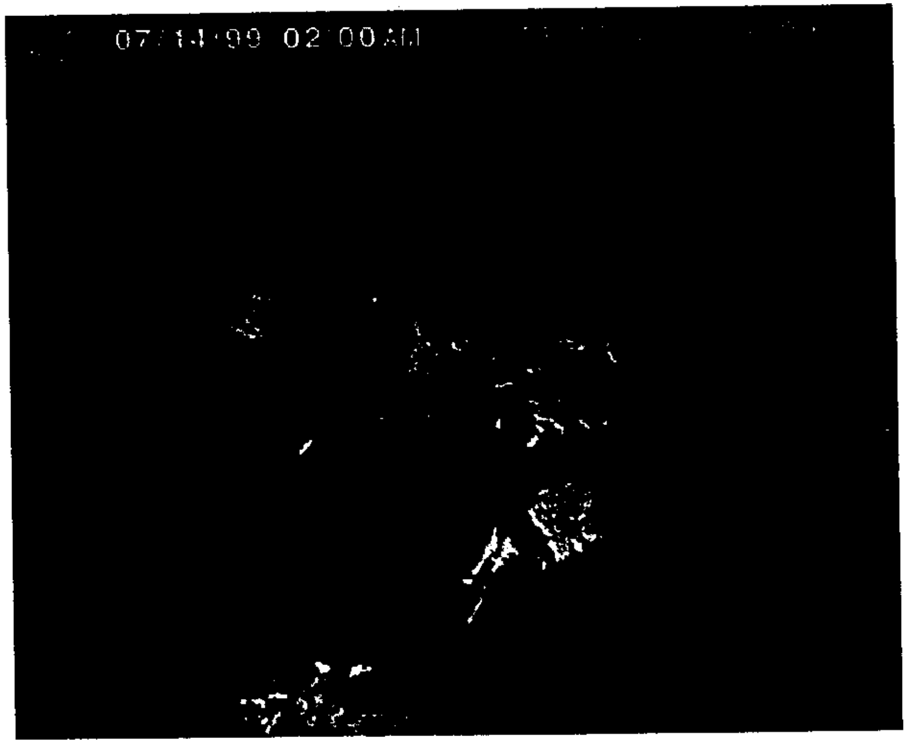
EM spectrum (μm)

Visible	NIR	SWIR	MIR	TIR	FIR

0.3 — 0.7 — 1.0 — 2.5 — 5.0 — 15 — 100

- **Spectral range from visible to far infrared**
- **Passive:**
  - **Imager:** takes broadband images
  - **Radiometer:** measures radiance
  - **Spectrometer:** measures spectra
  - **Spectral Imager:** takes narrow band images
  - **Sounder:** measures vertical profile
- **Active:**
  - **Lidar:** measures backscattered or reflected light

- On GEO satellites (36000 km):
  - Global monitoring
  - Short revisit time
  - Low spatial resolution



- On LEO satellites (300-1000 km):
  - Global monitoring
  - Long revisit time
  - High spatial resolution

- On LEO constellation:
  - Global monitoring
  - Short revisit time
  - High spatial resolution

MAIN APPLICATION FOR ATMOSPHERE SENSING

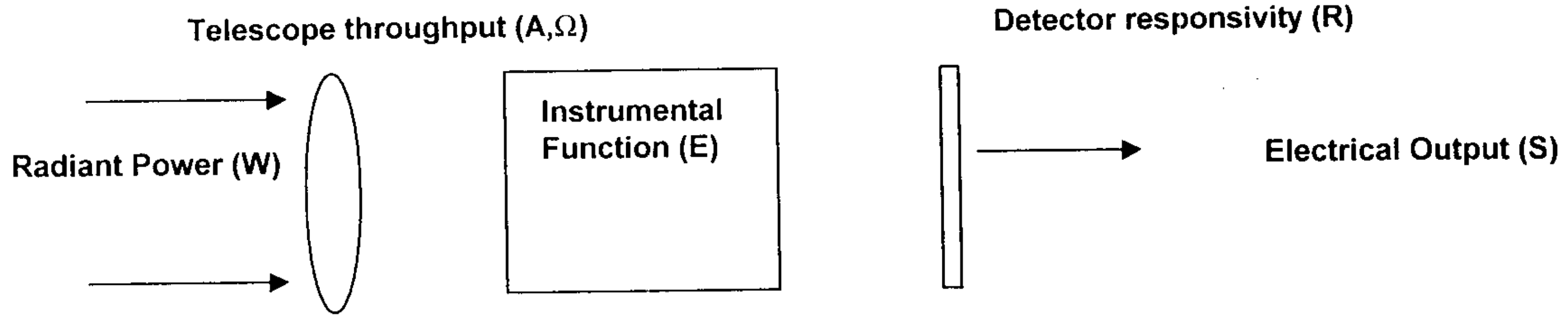
- **Meteorology – Weather forecast (Meteosat, GOES):**
  - Imagers in the visible and infrared
  - Temperature sounders
  - Humidity sounders
  - Cloud imagers/radiometers
  - Doppler lidar

- **Climatology – Earth radiation budget:**
  - Multiband radiometers
  - Imaging spectrometers

- **Atmospheric chemistry (ozone, trace gases, aerosols):**
  - UV/VIS spectrometers
  - IR/FIR spectrometers
  - Limb sounders

WHAT EO INSTRUMENTS MEASURE

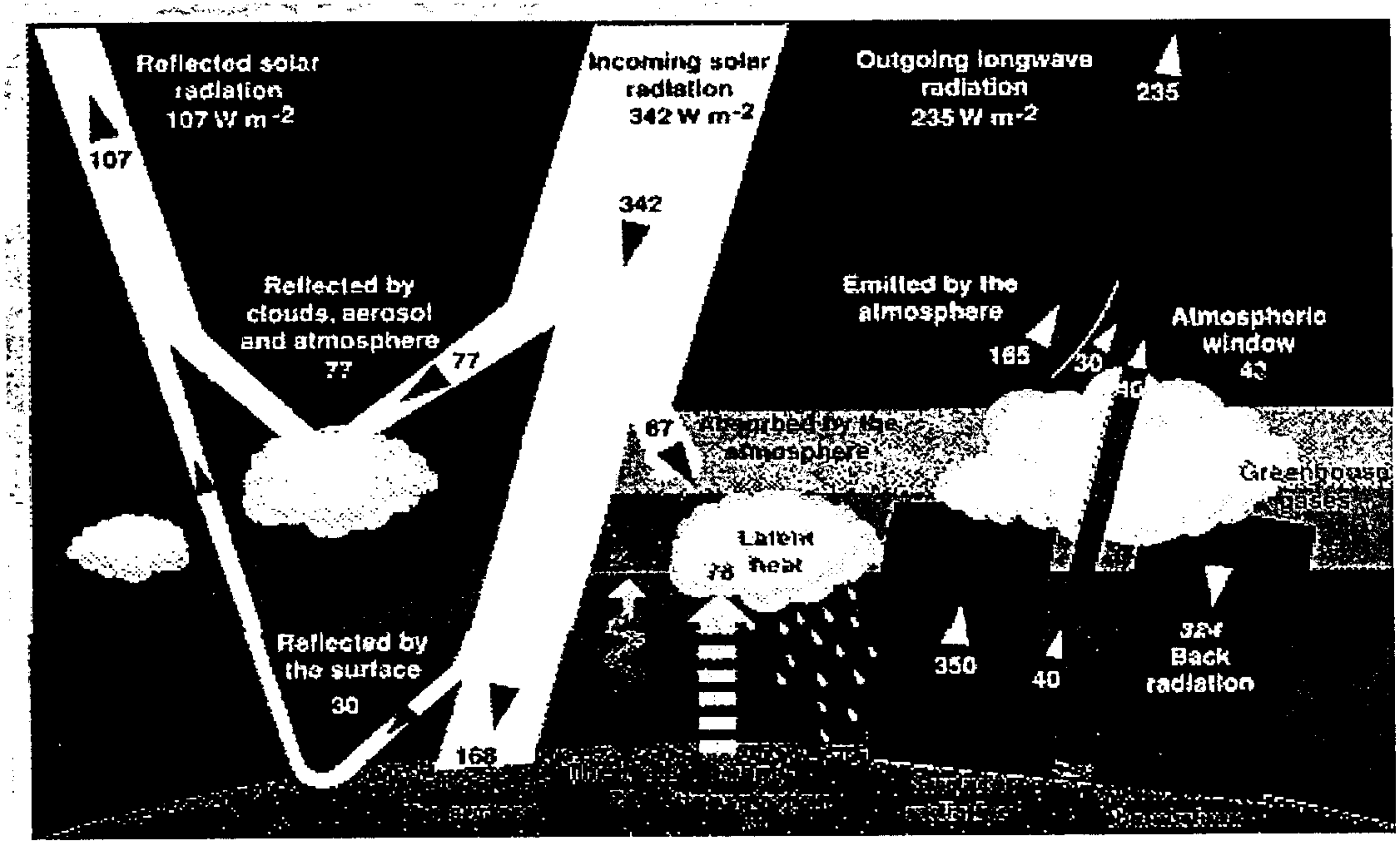
- Sensitive to radiant power entering the collecting optics



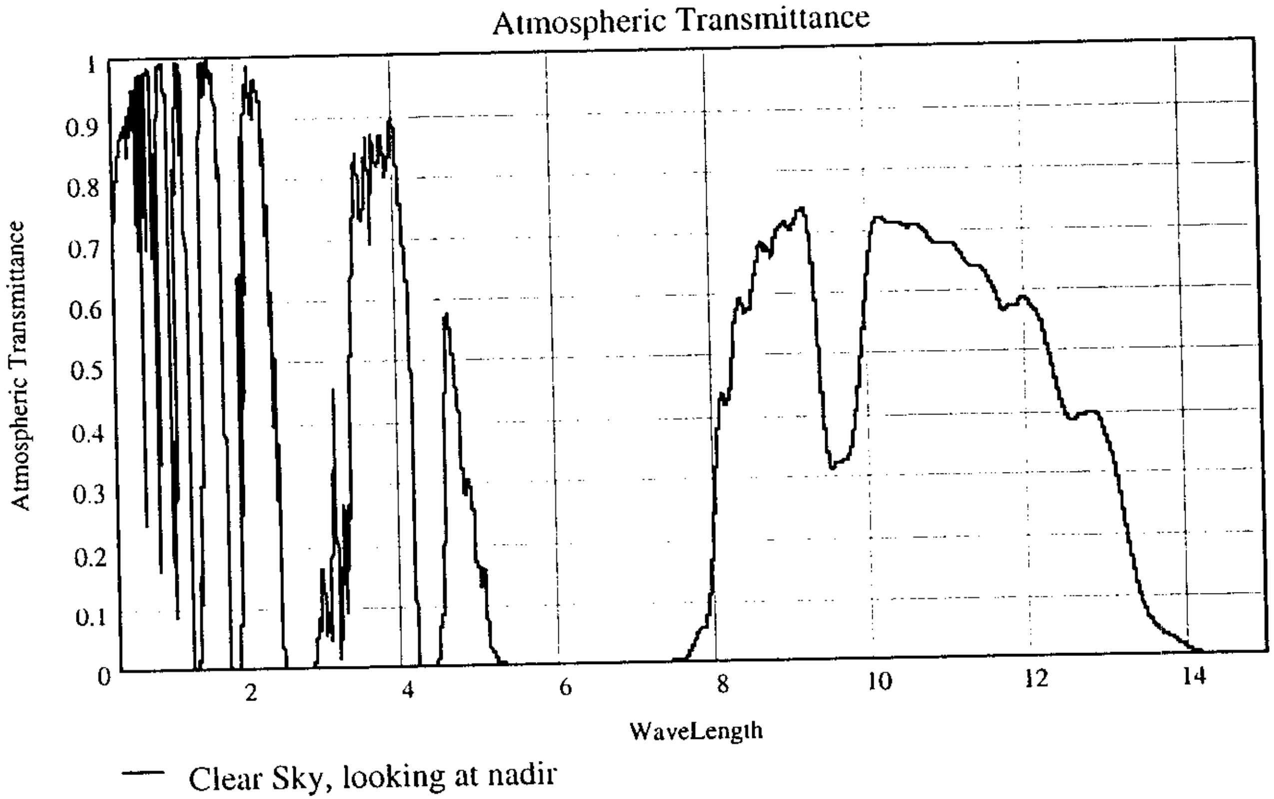
$$S(x,y,t,\lambda) = W(x,y,t,\lambda) \times E(\lambda) \times A \times \Omega \times R(\lambda)$$

- Not discriminating the radiant power contribution
- Atmosphere not uniformly transparent versus wavelength
- Output signal generally in the form of uncalibrated digitised electrical signal

RADIATION BUDGET

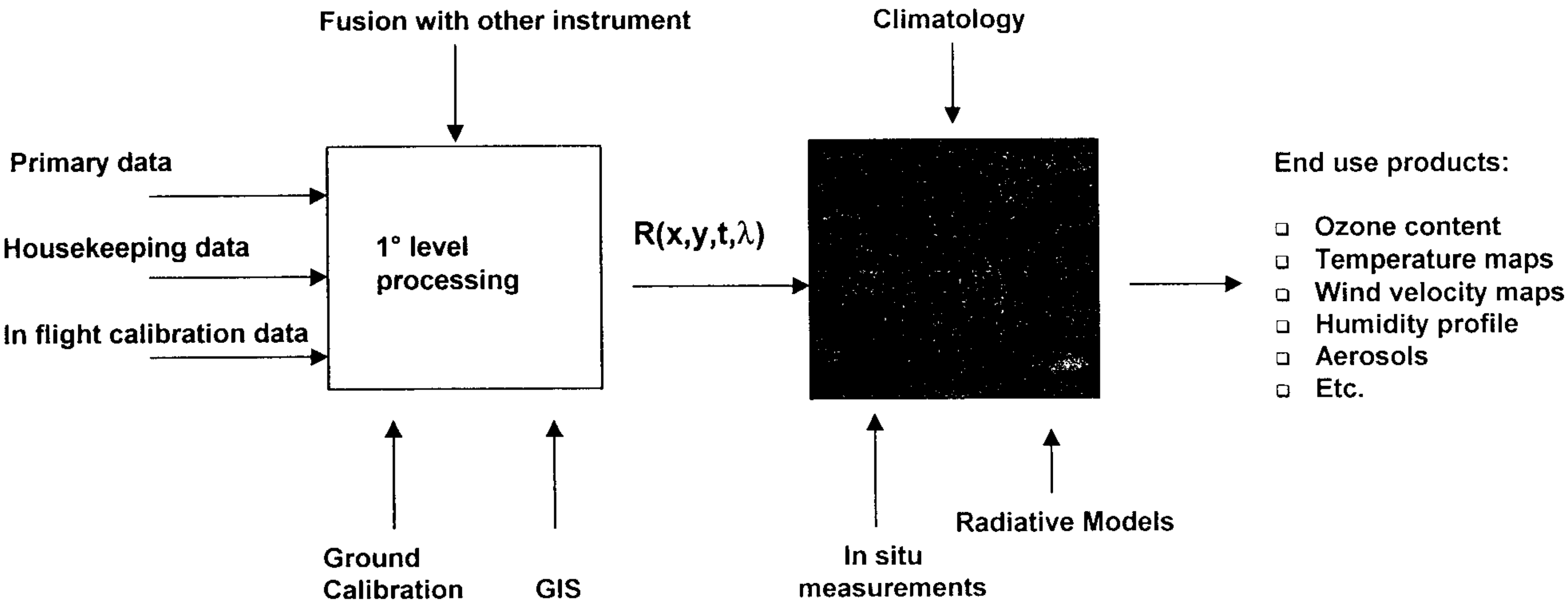


ATMOSPHERE TRANSMITTANCE



FROM RAW MEASUREMENT TO END USE PRODUCTS

- **Output signal from instrument (digitised electrical signal) requires processing to be converted into end use products (geophysical data)**

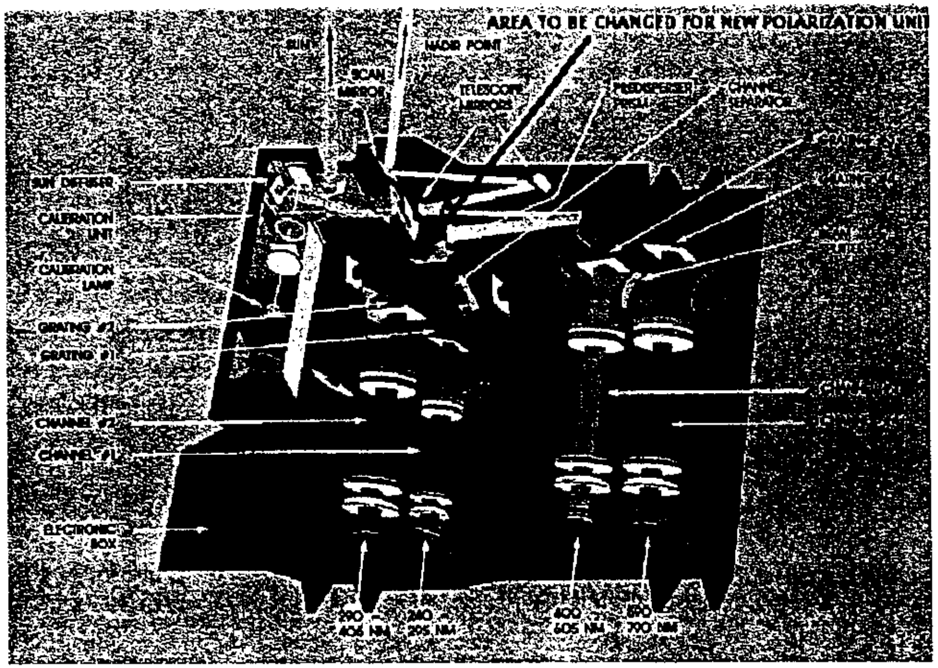


GLOBAL OZONE MONITORING EXPERIMENT (GOME)

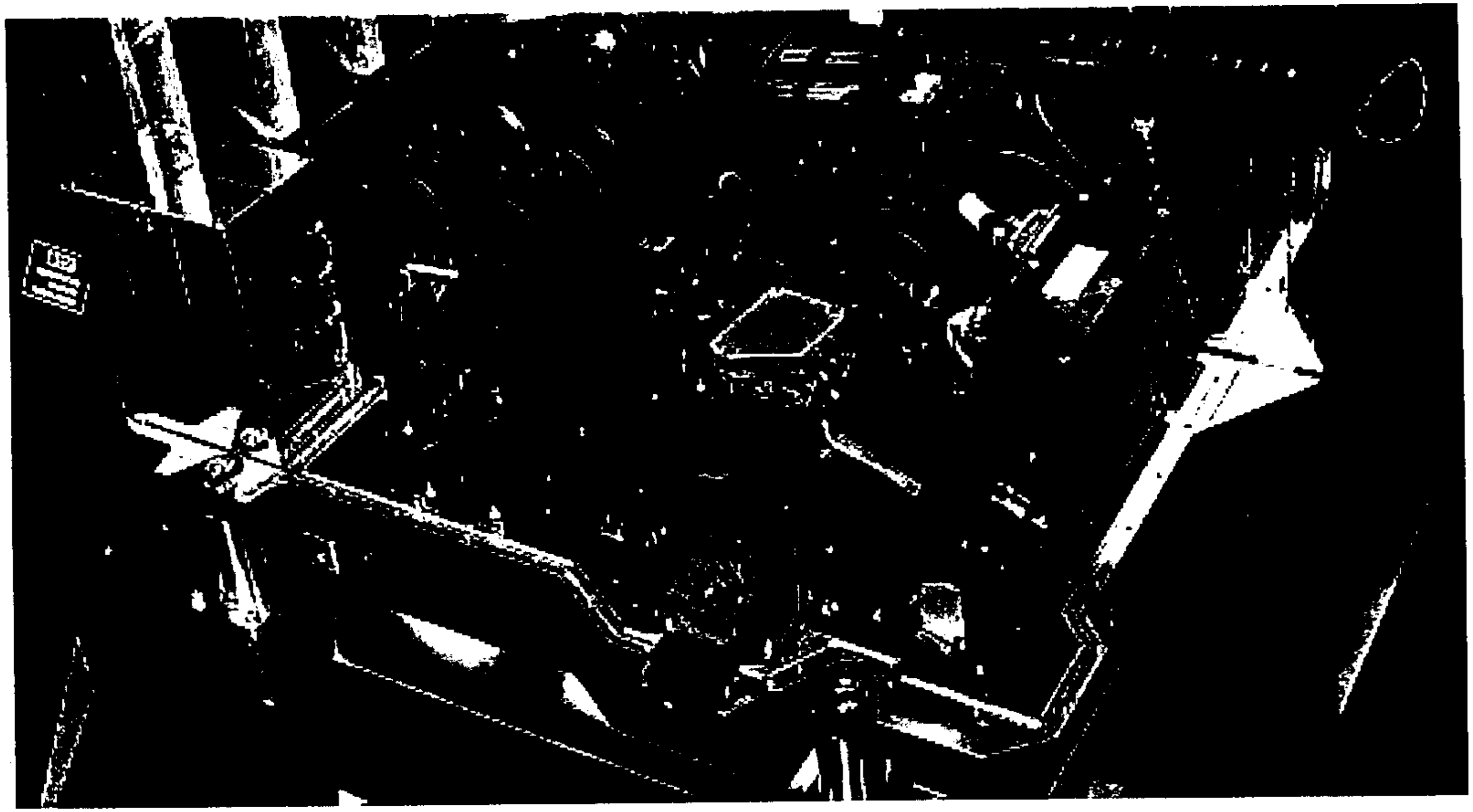
- ESA programme started in 1990 for the development of an ozone instrument for the satellite ERS-2
- Aimed to monitor the content in the atmosphere of ozone, trace-gases and aerosols.
- Officine Galileo BU-Space: Prime Contractor
- GOME flying on board ERS-2 from April 1995
- Improved version of GOME, called GOME-2, now in development to equip the new ESA/EUMETSAT satellites METOP

DESIGN

- **Nadir viewing scanning spectrometer**
- **Spectral range: 240-793 nm**
- **4 independent channels with spectral resolution of 0.2/0.4 nm**
- **Additional channels for polarisation measurement**
- **Scan mechanism for Earth scanning and pointing to calibration sources**
- **4 Si detectors of 1024 px each cooled at –40 °C**

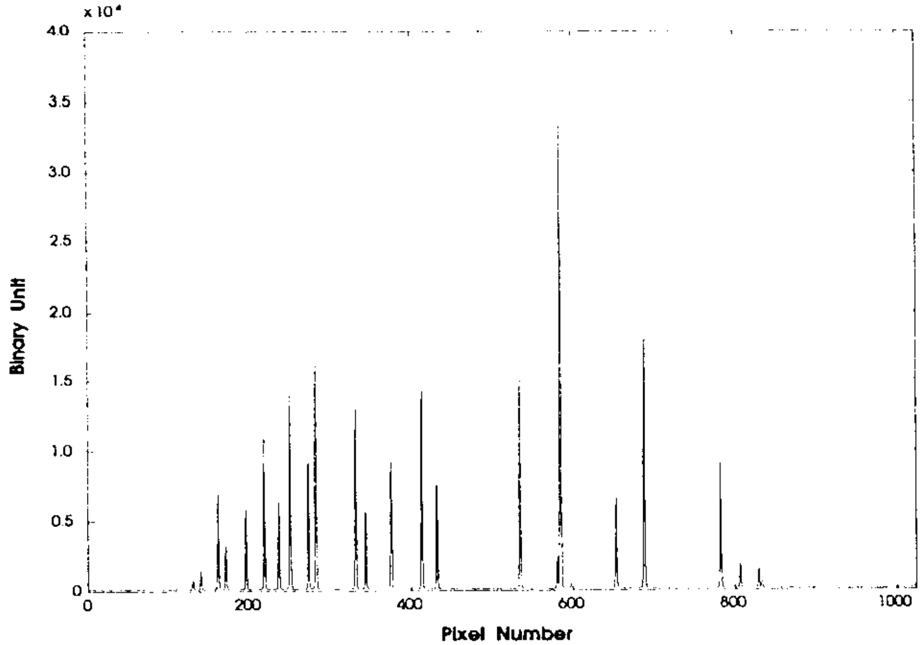


GOME INSIDE VIEW



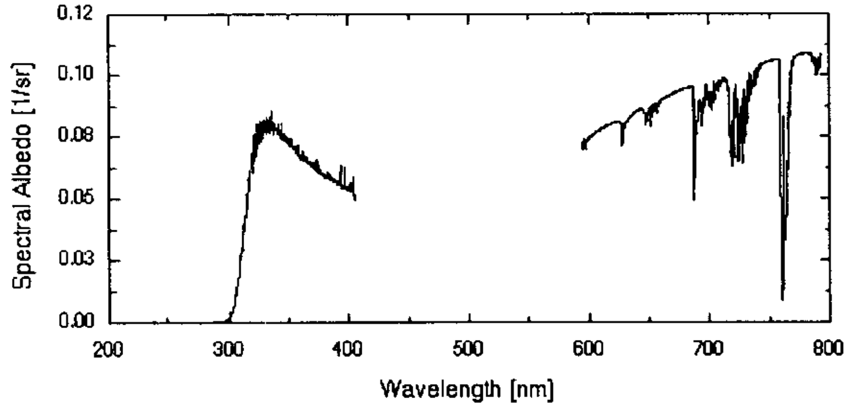
IN FLIGHT CALIBRATION

- Spectral lamp for spectral calibration
- White lamp for stability monitoring
- Sun diffuser for radiometric calibration
- Direct view of moon for radiometric calibration



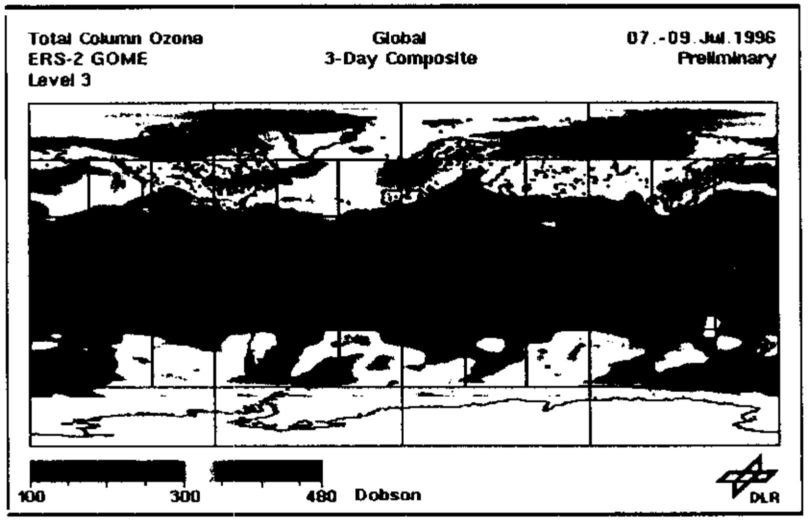
GOME PRODUCTS

- **Level 1:**
  - atmospheric radiance
  - ET solar radiance
  - Spectral albedo



- **Level 2: (DOAS retrieval method)**
  - total column ozone
  - total column NO2

- **Level 3:**
  - daily global ozone map
  - 3 days composite map
  - ozone profile



R E F I R

RADIATION EXPLORER IN THE FAR INFRARED (STUDY FUNDED BY EC)

Scientific objective: to measure radiative processes in the high troposphere (study and monitoring of the Earth Radiation Budget - Greenhouse Effect)

- ➔ study of H_2O distribution in mid and upper troposphere
- ➔ study of cirrus cloud radiative properties
- ➔ monitoring of longwave Earth emission tail
- ➔ improvement of radiative transfer models for operational use

Technique:

- Vertical sounding by spectral measurements at nadir in the 10-100 μm (FIR) band (basically on CO_2 and H_2O lines) by Fourier Transform Spectrometry

- Associated multi-spectral imaging in Visual and Infrared spectral bands for simultaneous cloud characterisation

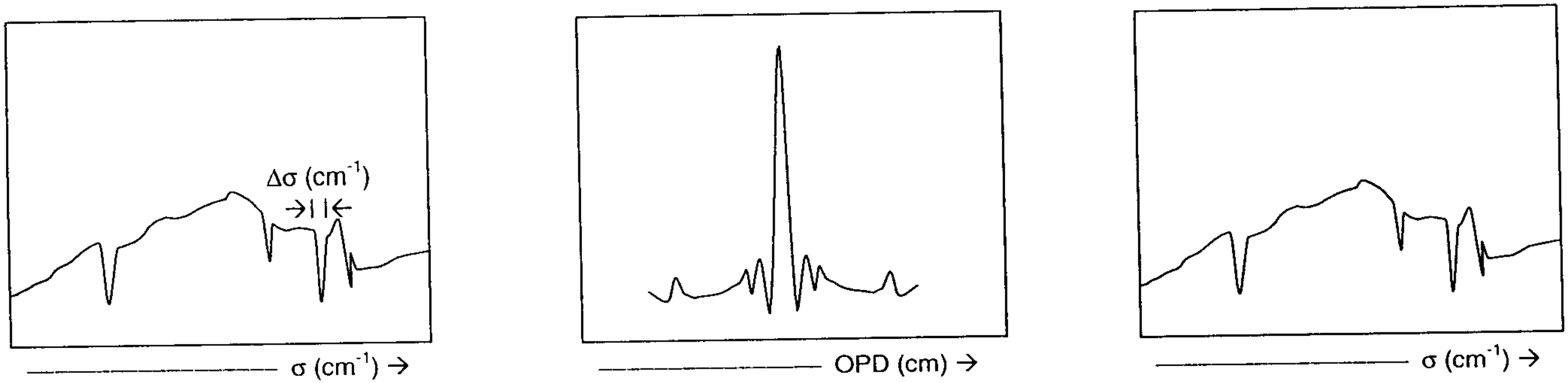
THE REFIR FOURIER TRANSFORM SPECTROMETER (RFTS)

Principle of Fourier Transform spectrometry:

Spectrum of input radiance → *Interferogram* → *Retrieved spectrum*

optical FT (interferometer)

numerical FT (digital processing system)



REFIR REQUIREMENTS

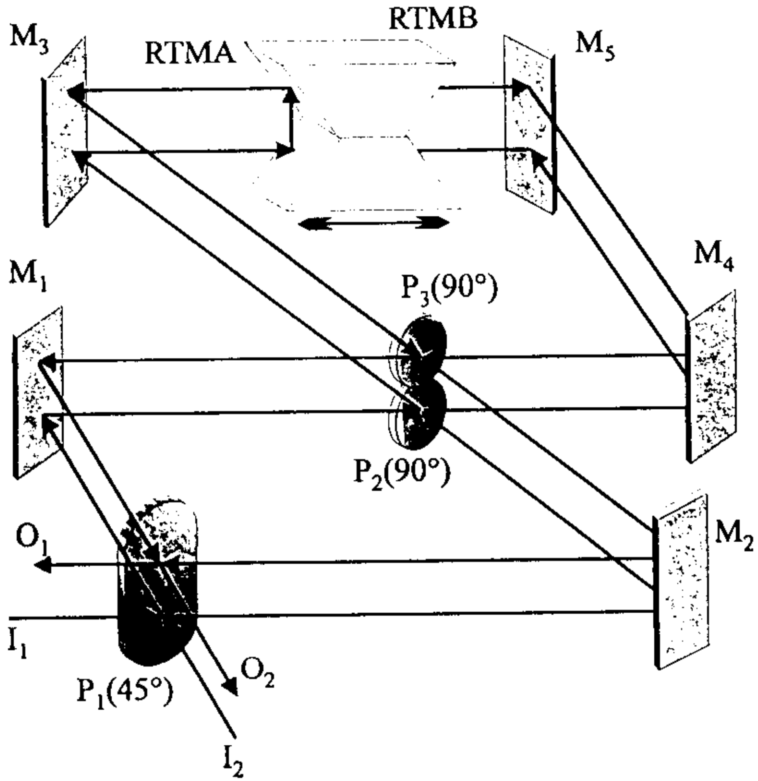
RFTS

- *Spectral range:* *100 – 1100 cm^{-1} (100 – 9 μm)*
- *Spectral resolution:* *0.5 cm^{-1}*
- *IFOV:* *10 km*
- *Sampling distance:* *50 km*
- *Signal to noise ratio:* *about 100 on the spectral range*

Multispectral Imager

- *Spectral range:* *VIS, SWIR, MIR, TIR (8 channels)*
- *IFOV:* *1 km*
- *FOV:* *32x32 km*

RFTS OPTICAL SYSTEM - INTERFEROMETER



Optical configuration scheme for the REFIR interferometer

Polarising beam splitter concept

Full compensation of tilt, partial compensation of lateral shift

Dual-input, dual-output interferometer

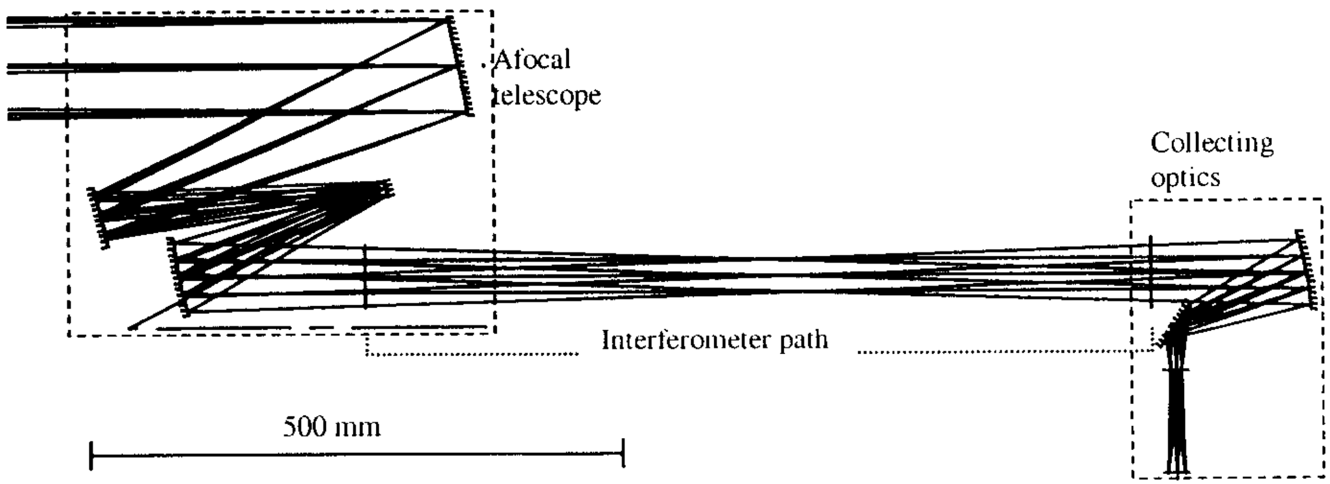
Dual input : scene, cold space (low sensitivity to instrument temperature fluctuations)

Dual output : improved SNR, rejection of common fluctuations, intrinsic redundancy

Uncooled concept using pyroelectric detectors

RFTS OPTICAL SYSTEM

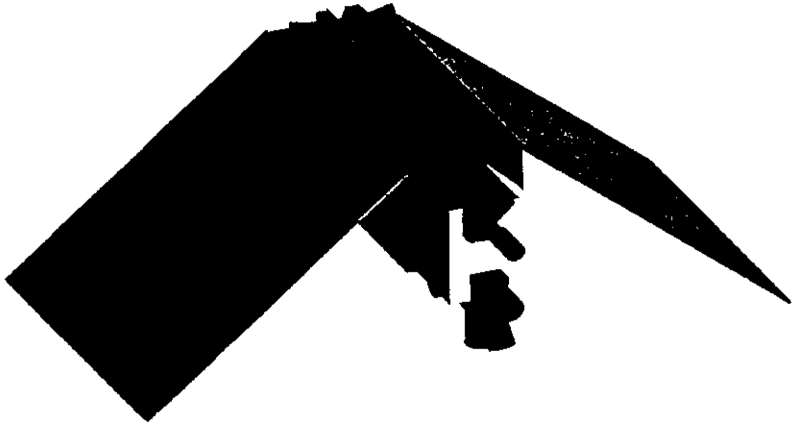
- Afocal Telescope — matching FOV and pupil to minimise the interferometer size – M=3
- Interferometric Assembly — performing optical Fourier Transform
- Focusing Optics — focusing output radiation
- Concentrators — optical coupling to detectors – Winston cones

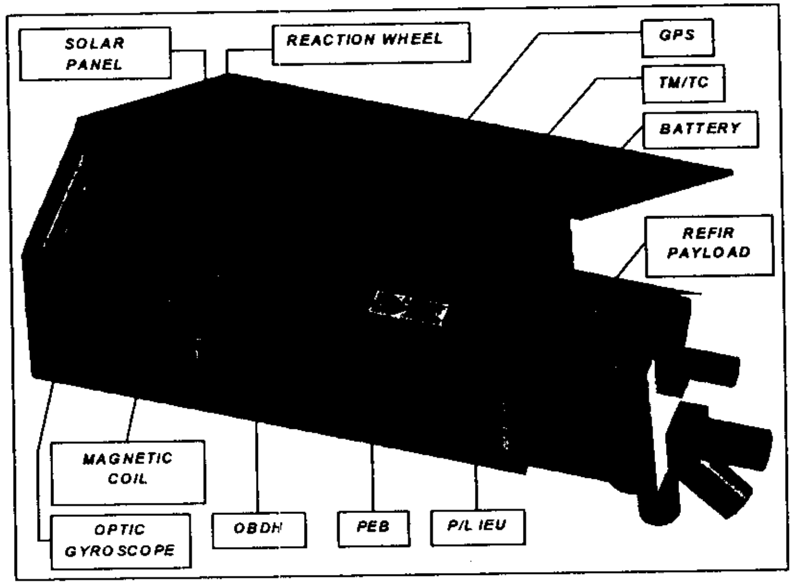


RFTS overall optical system (foldings in the interferometer path not represented)   *Interferometer – view from top*

REFIR AS A SMALL STAND-ALONE MISSION

Spacecraft layout (courtesy of Carlo Gavazzi Space S.p.A.)





MULTI SPECTRAL IMAGER (CLOUD IMAGER)

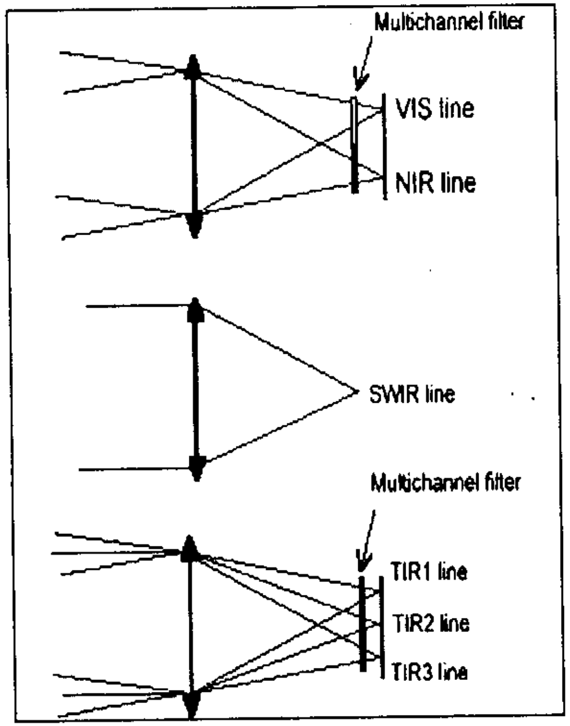
MAIN FEATURES, PURPOSE AND SCIENTIFIC PRODUCTS

- Is one of the two passive instruments in the suite of the ESA Earth Radiation Mission
- It provides, with a pushbroom technique, images of atmospheric scenes in 6 spectral channels:
  - reflected radiance in 3 VNIR and SWIR channels
  - emitted radiance in 3 TIR channels
- Narrow swath (100 km); Medium spatial resolution (1 km)
- Determination of clouds type, and of some microphysical parameters, such as cloud phase (Ice or water) throughout the following scientific products:
  - Cloud cover fraction
  - Optical thickness
  - Effective emissivity
  - Top temperature
  - Liquid water column

MSI MAIN REQUIREMENTS

Requirement	Value and comments
Orbit	SSO at 380 km LTDN: 13:00
Swath	100 km (design compatible with 300 km)
Spatial sampling interval	1 km
Spectral channels	VIS: 0.649 - 0.669 μ m NIR: 0.855 - 0.875 μ m SWIR: 1.580 - 1.640 μ m TIR 1: 8.5 - 9.4 μ m TIR2: 10.4 - 11.3 μ m TIR3: 11.4 - 12.3 μ m
Radiometric resolution	VNIR-SWIR: SNR > 200 for ρ =1.0 sun angle=15 deg TIR: NEdT < 0.25 K at 293 K
Absolute accuracy	VNIR-SWIR: better than 10 % TIR: better than 1 K

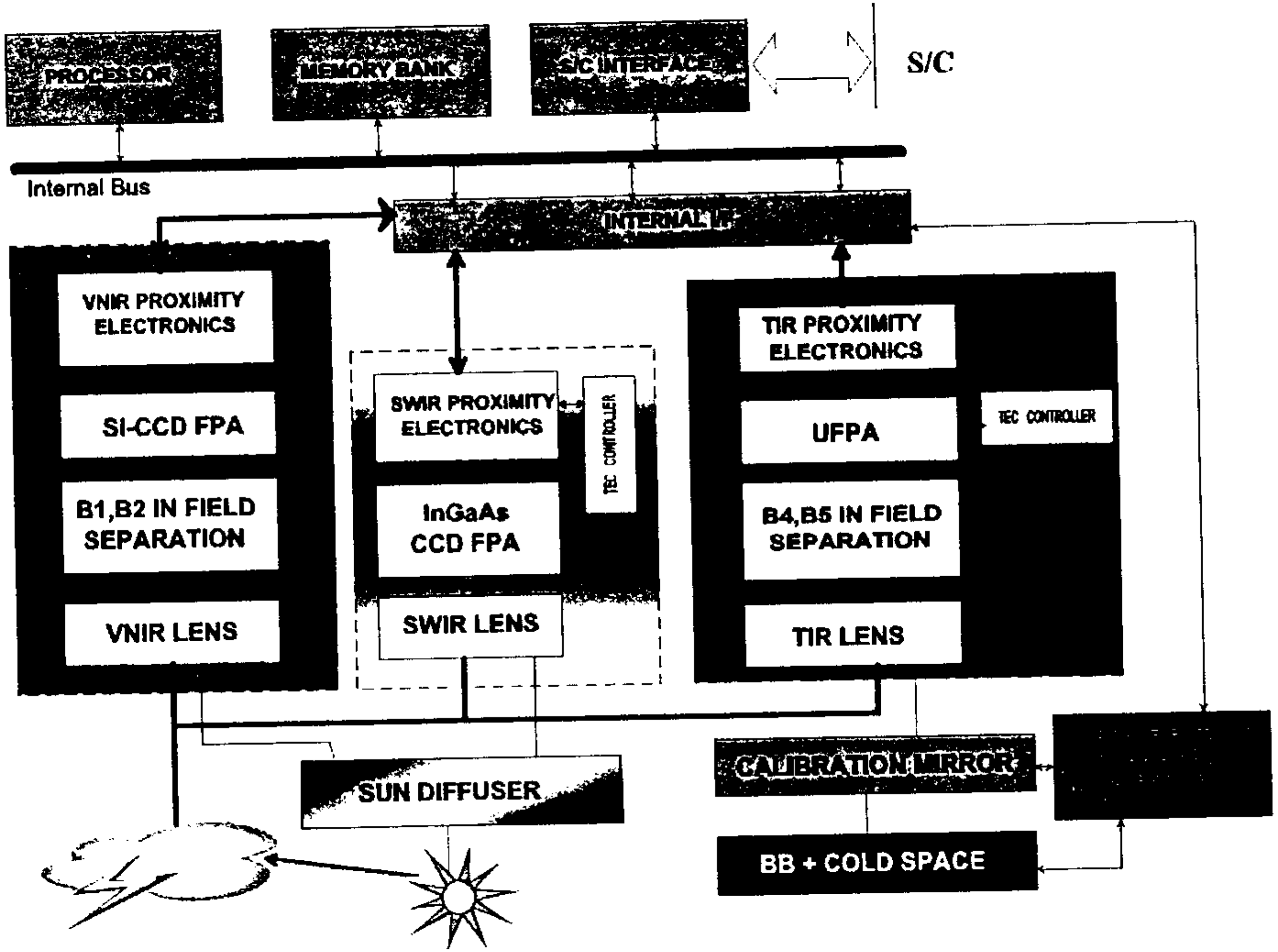
MSI INSTRUMENT DESIGN



	Ch1 VNIR	Ch2 SWIR	Ch3 TIR
Detector type	Si – CCD	InGaAs CCD	Microbolometers with CMOS ROIC.
FPA Baseline	2-D CCD	Linear array	Microbolometer
FPA Topology	2x288x384 area	Linear 299 px	320x240
Note	Already flown	Already flown	

Three different channels with in-field separation for VNIR and TIR bands

MSI FUNCTIONAL BLOCK DIAGRAM



MSI RADIOMETRIC PERFORMANCES

RADIOMETRIC RESOLUTION

Requirement:
SNR > 200 or
NEdρ < 5 10^{-3}
@ ρ =1

Requirement:
0.25 K

Channel	**VIS** 0.649 – 0.669 μ m		**NIR** 0.855 – 0.875 μ m		**SWIR** 1.580 – 1.640 μ m	
Reflectance ρ	1	0.1	1	0.1	1	0.1
NEd ρ (10^{-3})	**3.8**	3.5	**3.8**	3.5	**3.5**	3.5
Channel	**TIR1** 8.5 - 9.4 μ m		**TIR2** 10.4 – 11.3 μ m		**TIR3** 11.4 – 12.3 μ m	
Scene brightness T (K)	293	200	293	200	293	200
NEdT (K)	**0.13**	0.43	**0.15**	0.4	**0.14**	0.39

Radiometric resolution includes temporal noise, spatial noise, non-linearity effects and short-term drift.

RADIOMETRIC ACCURACY

VNIR-SWIR Accuracy » 5 %
TIR Accuracy » 0.5 K

MSI PHOTO REALISTIC VIEW