ECE 583

Lecture 27
Imaging Visible and Infrared Radiometers

Array Detector Imagers
Stereo Cloud Height & Winds Application
Why remote sensing -
Much of the atmosphere is inaccessible, at least for routine measurements.

From space, only way to provide large enough sample to large-scale view of the Earth system

AVHRR
SST anomalies
Nov 96,97
Measurement Requirements for Imaging Radiometers

• Spatial resolution (pixel size)
• Number and wavelength of channels
• Spectral width of wavelength channels
• Spatial alignment (registration) between wavelength channels
• Minimum signal measurement accuracy (%)
• Measurement accuracy of radiance (calibration)

Basic Type of Image Scanning Radiometer
Whiskbroom Imaging

Pushbroom Imaging

Grating Spectrometer Pushbroom Imaging
**MODIS**
Moderate Resolution Imaging Spectroradiometer

**MODIS TECHNICAL SPECIFICATIONS**

- **Orbit:** 706 km, 10:30 a.m. descending node or 2:30 p.m., ascending node, sun-synchronous, near-polar, circular
- **Scan Rate:** 20.3 rpm, cross track
- **Scan Dimensions:** 2330 km (cross track) by 10 km (along track at nadir)
- **Telescope:** 17.78 cm diam., off-axis, afocal (collimated), with intermediate field stop
- **Size:** 1.0 x 1.6 x 1.0 m
- **Weight:** 250 kg
- **Power:** 225 W (orbital average)
- **Data Rate:** 11 Mbps (peak daytime)
- **Quantization:** 12 bits
- **Spatial Resolution:**
  - 250 m (bands 1-2)
  - 500 m (bands 3-7)
  - 1000 m (bands 8-36)
- **Design Life:** 5 years

<table>
<thead>
<tr>
<th>Primary Use</th>
<th>Band</th>
<th>Bandwidth (nm)</th>
<th>Spectral Radiance (W/m²·sr)</th>
<th>Required SNR</th>
<th>Primary Use</th>
<th>Band</th>
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<th>Spectral Radiance (W/m²·sr)</th>
<th>Required SNR</th>
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<td>620 - 670</td>
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<td><strong>Land/Cloud</strong></td>
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<td>405 - 420</td>
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<td>26</td>
<td>1.36 - 1.39</td>
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<td>10.0</td>
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<td>915 - 965</td>
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<td><strong>Water Vapor</strong></td>
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<td><strong>Cloud Top</strong></td>
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- Bands 1 to 19, nm; Bands 20 to 36, μm
- SNR = Signal-to-noise ratio
- Performance goal is 30%-40%
- NEQVD = Noise-equivalent temperature difference

*SNR*
SOLAR DIFFUSER
STABILITY MONITOR (SDSM)

MAINFRAME
SOLAR DIFFUSER
SPECTORADIOMETRIC CALIBRATION ASSEMBLY (SRCA)
BLACKBODY
MAIN ELECTRONICS MODULE (MEM)
SPACE VIEW
RADIATIVE COOLER
FOLD MIRROR
RADIATIVE COOLER DOOR

*ENTIRE MAINFRAME NOT SHOWN IN CUT-AWAY FOR CLARITY*
**Specifications of the MISR Instrument**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td>Mission life</td>
<td>6 years</td>
</tr>
<tr>
<td>Instrument mass</td>
<td>148 kg</td>
</tr>
<tr>
<td>Instrument power</td>
<td>Approximately 117 W peak, 75 W average</td>
</tr>
<tr>
<td>Data rate</td>
<td>3.3 Megabits/second average, 9.0 Megabits/second peak</td>
</tr>
<tr>
<td>Global coverage time</td>
<td>Every 9 days, with repeat coverage between 2 and 9 days depending on latitude</td>
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<tr>
<td>Crosstrack swath width</td>
<td>360 km common overlap of all 9 cameras</td>
</tr>
<tr>
<td>Nine pushbroom cameras</td>
<td>Named An, Af, Aa, Bf, Ba, Cf, Ca, Df, and Da where fore, nadir, and aft viewing cameras have names ending with letters f, n, a respectively and four camera designs are named A, B, C, D with increasing viewing angle respectively</td>
</tr>
<tr>
<td>View angles</td>
<td>0, 26.1, 45.6, 60.0, and 70.5 degrees</td>
</tr>
<tr>
<td>Spectral coverage</td>
<td>4 bands (blue, green, red, and near-infrared)</td>
</tr>
<tr>
<td>Detectors</td>
<td>Charge Coupled Devices (CCDs), each camera with 4 independent line arrays (one per filter), 1504 active pixels per</td>
</tr>
</tbody>
</table>
Example of MISR Level 2TC data product
Hurricane Debby

*Level 2 Top-of-Atmosphere/Cloud Product*
This contains measurements of cloud heights and winds, cloud texture, top-of-atmosphere albedos and bidirectional reflectance factors, and other related parameters.
Low Earth Orbit Stereo Imagers

**VISIBLE**
MISR – visible push broom imager, large angle separation tri-angle wind retrieval

**THERMAL INFRARED**
ATSR – 45° conical scan, 120 sec image separation, ESA

ISIR – 8-12° angle separation, ¼ km resolution, 90 km cross track 260 km orbit height, STS-85

ICIR – 10° angle separation, 0.65 km resolution, 1400 km cross track 820 km orbit height, Proposed
Planck's blackbody function

The nature of $B_\lambda(T)$ was one of the great findings of the latter part of the 19th century and led to entirely new ways of thinking about energy and matter. Early experimental evidence pointed to two particular characteristics of $B_\lambda(T)$ which simplify calculations.

\[
B_\lambda = \frac{2\pi hc^2}{\pi \lambda^5 \left( e^{\frac{hc}{\lambda kT}} - 1 \right)}
\]

\[
B_\lambda = \frac{C_1}{\pi \lambda^5 \left( e^{\frac{C_2}{\lambda T}} - 1 \right)}
\]

\[
C_1 = 2\pi hc^2 = 3.7141832 \times 10^8 \text{ W} \cdot \mu\text{m}^4 \cdot \text{m}^{-2}
\]

\[
= 3.7141832 \times 10^4 \text{ W} \cdot \mu\text{m}^4 \cdot \text{cm}^{-2}
\]

\[
= 3.7141832 \times 10^{-4} \text{ W} \cdot \text{nm}^4 \cdot \text{m}^{-2}
\]

\[
C_2 = \frac{hc}{k} = 14387.86 \mu\text{m} \cdot \text{K}
\]
Brightness temperature

An important temperature of the physical system, and one different from the thermodynamic temperature in general is the temperature that can be attached photons carrying energy at a fixed wavelength. If the energy of such is $I_\lambda$, then this temperature is

$$T_\lambda = B^{-1}(I_\lambda) = C_2/\{\lambda \ln[I_\lambda \lambda^5 \pi/C_1 + 1]\}$$

which is referred to as the brightness temperature.

The brightness temperature of microwave radiation is proportional in a simple way to microwave radiance:

Rayleigh Jeans Law $\lambda T \rightarrow \infty$

$B(T) \rightarrow kT$

The spectral brightness temperature of planets and moons
IR Stereo Imager Development
Global Infrared Stereo Observations by LEO UMAD Imaging Radiometer

ISIR Shuttle Hitchhiker Experiment
COVIR Instrument Incubator
Multi Layer Stereo Retrievals
Application: 
Diurnal Variation in Cloud Height Distribution

Diurnal variation is a huge factor for cloud distributions.

The best passive retrievals use visible plus IR channels, not possible at night.

IR only CO$_2$ slicing retrievals are limited in resolution.

Active sensors, lidar/radar, now measure nadir only.

Scanning radar/lidar is high cost and limited to a few 100 km’s.
The impact of satellite-derived polar winds in global forecast models

David A. Santek, CIMSS/Univ. of Wisconsin, Madison, WI

The use of Atmospheric Motion Vectors (AMVs) in Numerical Weather Prediction (NWP) models continues to be an important source of information in data sparse regions. These AMVs are derived from a time-sequence of images from geostationary and polar orbiting satellites. NWP centers have documented positive impact on model forecasts not only in regions where the AMVs are measured, but elsewhere as well. One example is the effect of the Moderate Resolution Imaging Spectroradiometer (MODIS) polar winds on forecasts in the middle and subtropical latitudes. Feature-tracked winds derived from a time-sequence of MODIS satellite imagery over the polar regions are routinely input into many operational global numerical models. These NWP centers report that the winds have a positive impact on forecasts not only in the polar regions, but also into mid- and lower-latitudes, especially in 3 to 5 day forecasts. However, the impact differs for different models.

Side-by-side experiments were run, with and without MODIS polar winds, using the National Centers for Environmental Prediction's (NCEP) Global Forecast System (GFS) and the Navy's Operational Global Atmospheric Prediction System (NOGAPS) models. Output from these experiments was analyzed by using a combination of model analyses and forecasts, with sophisticated visualization techniques, to determine the impact to global model fields. The differences in these model fields between the GFS and NOGAPS due to the inclusion of the MODIS winds are explained by data thinning, weighting of the wind observations, and characteristics of their respective assimilation systems.
Objectives:

- Develop Compact, Low Cost and Rugged Imaging Infrared Cloud Radiometers
- Test the Application of Uncooled Microbolometer Focal Plane Arrays for Space Borne Imaging Applications
- Observations For Cloud Science: Obtain Combined Passive/Active Remote Sensing From Joint Shuttle Flight with the SLA Lidar

Specifications:

- Microbolometer array detector eliminates cooling requirements
- Push broom imaging eliminates mechanical scanning
- Time delay integration improves NEDT by the square root of the along track detector elements
- 8, 11, 12 & 7-14 μm channels, 0.1-0.01°K NEDT, 250 m resolution, 82Km swath

Microbolometer Array
SIM100 Uncooled Imaging Module

Technical Specifications

- DETECTOR SPECTRAL RESPONSE: 8-14 μm
- ARRAY FORMAT: 327 x 245 pixels
- PIXEL PITCH: 46.25 μm
- F/# COMPATIBILITY: 0.8 to 4.0
- NETD (f/1, 30 Hz, 80% τ): 40 mK
- FRAME UPDATE RATE: 60 Hz
- DETECTOR TIME CONSTANT: 12 ms
- POWER: 8.0 W
- SIGNAL PROCESSOR: 4.0 x 6.0 x 1.3 in.

327 X 245 Array
Uncooled Microbolometer Array Detector (UMAD) Technology was originally declassified in about 1990.

The ISIR detector was the second pre-production array produced by Loral Space Systems.
Uncooled Microbolometer FPA

3. Temperature Sensitive Transducer Material (VOx)

3. Temperature rise causes resistance change

1. Isolated Microbridge Structure

absorbs IR radiation, temperature increases rapidly

2. Supporting Leg

provides electrical contact & thermal isolation

4. CMOS Pixel Readout Circuitry

converts resistance change into electrical signal
ISIR Imaging

Channels: 8.2 - 9.0 µm  
10.3 - 11.3 µm  
11.5 - 12.5 µm  
8.0 - 12.5 µm

Nominal Spatial Resolution: 250 m  
Swath Width: 87 km

Time Delay Integration

NEDT is reduced by the square root of the integrated along track detector elements.

IMAGE SMEAR FACTORS

- Roll Motion
- Incorrect TDI Altitude
- Cross Track Velocity (Incorrect Yaw)

Altitude ~ 250 km

Every 1/30th of a second the image moves one pixel across the array and a new frame is added to the buffer.
ISIR - Time Delay and Integration (TDI)

Figure 4
UNCOOLED ISIR NEDT vs. NO. OF TDI PIXELS

NEP=35 pW (1993 Honeywell measurements)
50mm, f/0.73 optics
IFOV = 0.9 m"
k_TDI = 0.6

BASELINE TDI x 40

11.5-12.5µ (AVHRR5)
10.3-11.3µ (AVHRR3)
8.2-9.2µ
7-13µ (wideband)
AVHRR regr.
Instrument Design

CALIBRATION BLACK BODY

CALIBRATION ASSEMBLY

CALIBRATION DRIVE MOTOR

IRIS DRIVE MOTOR

50 mm LENS ASSEMBLY

DETECTOR ARRAY and FILTER WHEEL

FILTER WHEEL DRIVE MOTOR

ZnSe WINDOW

ISIR SENSOR ASSEMBLY

UPPER END PLATE

ADAPTER PLATE

RECORDING DEVICE

LOWER END PLATE
Image Signal as a Function of Lens/Telescope F#

\[ P_{\text{pix}}(\lambda) = I(\lambda) \ A \ \Omega \ T_{\text{sys}} \]

\[ A = \pi \frac{D^2}{4} \ \ \ \ \ \ D = \text{Lens Diameter} \]

\[ \Omega = \pi \frac{(d/L)^2}{4} \ \ \ \ \ d = \text{Pixel Diameter} \]

\[ L = \text{Focal Length} \]

\[ P_{\text{pix}}(\lambda) = I(\lambda) \left( \frac{d \pi}{4F#} \right)^2 \]

Low F# lens gives brightest image-needed for higher noise detectors.

ISIR Lens: F = .73
Theoretical Minimum F = .6
ISIR OPTICS, DETECTOR ARRAY, FILTER WHEEL ASSEMBLY AND ROTATION STAGE

50 mm, f/0.73 Infrared Optics

Uncooled Microbolometer Detector Array
(Courtesy of Loral Infrared & Imaging Systems)

Removable Filter Wheel Assembly on Detector Mount

Filter Wheel and Detector Array on Rotation Stage
ISIR INSTRUMENT AND CALIBRATION SYSTEM

ISIR Instrument

Calibration Mirror Assembly

Inflight Calibration System
ISIR prior to shuttle Hitchhiker bridge installation

8 mm tape drive
Space Shuttle Experiment for Uncooled IR Array
Infrared Spectral Imaging Radiometer (ISIR)

STS-85 Experiment Results

- Successful Microbolometer TDI infrared imaging
- First Global multispectral IR data set at 1/4 Km resolution
- IR data supported by Shuttle Laser Altimeter Cloud Heights
Space Shuttle Experiment for Uncooled IR Array
Infrared Spectral Imaging Radiometer (ISIR)

Surface Observations

- Land Emissivity
- Ocean Temperature
Shuttle Roll Maneuvers with ISIR in Video Camera Mode
ISIR 10.8 um Channel
(Coast of New Jersey)
ISIR
Multispectral Analysis

Cirrus Particle Size from IR Split Window Brightness Difference
ISIR on STS-85

- Proved uncooled IR array detectors for space
- First global multispectral IR data set at 1/4 Km resolution
- Global cloud science with laser altimeter cloud heights

Sensor Tested for Environmental Surveillance

Device Could Lead to Simpler, Cheaper Satellites

COMMENTARY

Worthwhile Research

The recent test aboard the space shuttle of a low-cost infrared sensor is an excellent use of NASA funds and a terrific example for the agency to follow as it establishes priorities and makes decisions for the years ahead.

The sensor, called the Infrared Spectral Imaging Radiometer (ISIR), is far more cost-effective than some of the projects NASA wants to fund, such as liquid fly-back boosters for the shuttle.
Mars Surface Imager Based On Microbolometer array detector

**Benefits**

- Determines the mineralogy and petrology of localized deposits associated with hydrothermal or subsurface environments, and identifies possible sample return sites likely to represent these environments.

- Provides a direct link to the global, hyperspectral mineral mapping from the Mars Global Surveyor Thermal Emission Spectrometer (TES).

- Studies small-scale geologic processes and landing site characteristics using microscopic and thermophysical properties.

- Ability to search for temperature anomalies associated with active subsurface hydrothermal systems.

**THEMIS**

THEMIS is a 12 kg, 14W pushbroom imager for NASA's Mars 2001 Orbiter Mission. THEMIS acquires data in 9 IR bands from 6.5 to 15.5 μm at 100m resolution. These images, generated by Dr. Philip Christensen at Arizona State University (ASU), are used to map mineralogy and search for hydrothermal activity. Santa Barbara Remote Sensing (SBIRS) also integrated the Malin Space Science Systems Visible Imaging Sensor (VIS) into THEMIS.

Using the VIS, THEMIS provides visible images with 20m resolution in 5 bands from 0.4 to 0.8 μm. The imagery and data from THEMIS was instrumental in the selection of landing sites for subsequent Mars sample collection and return missions.

An entirely new space-based longwave IR (LWIR) imaging sensor. THEMIS uses uncooled silicon microbolometer LWIR detector technology to address the demanding requirements of a planetary science mission. The advantage of these modern IR detectors is that no cryogenic cooler is required.

**Mars Surveyor 2001**

The Mars Surveyor 2001 Orbiter was launched in March, 2001. After a propulsive maneuver into a 25-hour capture orbit, aerobraking was used over the next 78 days to achieve its orbit at an altitude of 400 km above the Martian surface. The Orbiter carries three science instruments: THEMIS, the Gamma Ray Spectrometer, and the Mars Radiation Environment Experiment. THEMIS maps the mineralogy and morphology of the Martian surface using a high-resolution camera and a thermal infrared imager.

**Objectives**

To determine the mineralogical composition of the surface for minerals whose abundance is approximately 1 km and provide information on the morphology of the surface such that features significantly less than 1 km can be adequately resolved.

**Science Team**

The Principal Investigator is Dr. Philip Christensen at ASU. Co-investigators are Bruce Jakosky, Hugh Kieffer, Mike Malin, Harry McSween, and Kenneth Nealson.

**Suppliers**

ASU, SBIRS, Raytheon Vision Systems, and Malin Space Science Systems. Greg Methot is the Instrument Manager at ASU.
Stereo Height Retrieval

Figure 2. Stereo overlap of ISIR image frames acquired at 8.6 and 12 mm roughly 3.5 seconds apart. This gives 50% overlap and complete ground coverage between the two spectral bands.

calculate the height of any feature in the overlapped region from its measured parallax in pixels as:

\[ h = H - \frac{B}{\delta \theta} \]
Stereo Height Retrieval

This quantification begins by locating common features in the imagery from a pair of spectral channels. In doing so one of the images is defined to be the “reference image” and the other to be the “search image.” The reference image is divided into a regular grid of smaller subimages, or “patches,” that are compared to identically sized areas within a select window of the search image. With each comparison a value of $\chi^2$, defined as

$$\chi^2 = \frac{1}{N} \sum (y_i - x_i)^2,$$

where $x_i$ and $y_i$ are the values of the $i$th pixel within the reference and search image patches and $N$ is the number of pixels included in the patch region, is calculated. The average values of $x$ and $y$ for a select patch are subtracted from $x_i$ and $y_i$ prior to calculating $\chi^2$ to account for differences in the absolute brightness of different patches. The best match is assumed to be found when $\chi^2$ is at a minimum. There is no threshold for acceptance of $\chi^2$ and a minimum of two pixels is needed to define the brightness variation that makes up a patch with the presence of noise increasing this requirement.

Lancaster et al., 2003
The depth resolution attainable with this method can be expressed in terms of the range-to-baseline ratio and the IFOV. For ratios greater than 30, the depth resolution degenerates to one baseline. The equation below shows the relationship between baseline $B$; range $Z$; IFOV, and depth resolution $\Delta Z/B$, for a pixel located at the center of the overlapped region. Simple geometry and trigonometry results in the expression:

$$\Delta Z / B = \frac{1}{2} \left( \frac{1}{\tan(\arctan(\frac{B}{2Z}) - \frac{\theta}{2})} - \frac{1}{\tan(\arctan(\frac{B}{2Z}) + \frac{\theta}{2})} \right)$$

This equation can be used to give height uncertainty in km as a function cloud height $h$, by replacing the range $Z$ with ($H - h$). The figure shows the results for an altitude of 266 km, a baseline of 25.9 km and 0.903 milliradian IFOV. For a single-pixel cloud at 10 km altitude, the height uncertainty would be $\pm$ 2.3 km (without using a sub-pixel algorithm to search for the parallax giving the best correlation between views).

Depth resolution expressed as $\pm$ height uncertainty for clouds ranging between sea level and 20 km. Graph is for ISIR stereo imaging.
ISIR
Cloud Heights from Stereo Analysis Compared to Shuttle Laser Altimeter Cloud Heights

280 K

240 K

Measured with SLA

Laser

Inferred from ISIR

Stereo

Elapsed Time (seconds)
Issues for Stereo Accuracy

Measurement physics:
• Photon penetration / Distributed source function
• Multi cloud layers
• Cloud top contrast
• Cloud motion

Instrument issues
• IFOV and stereo view separation
• NEDT

Height uncertainties driven by measurement physics
Stereo Cloud Heights From Multispectral IR Imagery via Region-of-Interest Segmentation

Kathrine F. Manizade, James D. Spinhrne, Member, IEEE, and Redgie S. Lancaster

**Figure 4.** Composite imagery at 8.6 and 12 um, comprised of two frames in each band. Only the regions of overlap are shown. The motion of the ISIR sensor is from the bottom towards the top of the panels.

**Figure 5.** Brightness temperature histograms of composite thermal images in Figure 4.
Figure 6. Binary ROI (region-of-interest) masks for the stereo pair in Figure 4 are shown, created by assigning a value of 1 to all pixels at or below the indicated brightness temperature, and 0 to all pixels above that temperature. The highest clouds are in the masks at the top of the frame, and are arranged in order of increasing temperature, and hence decreasing altitude.
Figure 8. Discrete height maps generated from ROI masks and stereo retrieval. The altitudes are tabulated in the table above.
Figure 12. 8 um stereo height composite and line plot of stereo heights along nadir column for composite image obtained between 8:17:18:55:31 to 8:17:18:58:04 GMT, or from 90 W, 50 N, to about 60 W, 30 N.
Objective: Identify common cloud layers for stereo height retrieval

Approach: Exploit correlation between infrared $T_B$ and cloud height
- Define cloud mask based up $T_B$
- Identify parallax shift for cloud mask thru pattern matching
- Assign retrieved height to all pixels enclosed by mask

Result: Stereo height retrieval for multiple cloud layers

Manizade et al., 2005
Free Flyer Prototype Development
Compact Visible and Infrared Radiometer

- $\frac{1}{2}$ km resolution from 600 km
- Four IR channels between 3.5 and 12.5 µm
- IR detector: Uncooled, microbolometer Focal Plane Array
- Time Delay and Integration to improve S/N
- 0.1ºK accuracy at 300 K
- Up to four visible channels between 440 and 860 nm
- Visible detector: Uncooled, CCD linear array
- Mass: 20 kg; Power: 35 W

• Separate visible and infrared cameras
• Array detector pushbroom imaging
COVIR Design Upgrades

Move from a filter wheel design to using strip filters

- Eliminates dead time between filters
  - Allows for inclusion of 4th passband with TDI 15
- Eliminates possible mechanical failure of the filter wheel.
  - Provides greater reliability
Detector Specifications

**Infrared**
- Type: Uncooled microbolometer FPA
- Format: 327 x 240
- Operation: Time Delay and Integration
- Channels: 4

**Visible**
- Type: CCD linear array
- Format: 4 rows of 1x1520
- Operation: Continuous readout
- Channels: 4

Figure 3 Microbolometer array with strip filters

8.0 - 9.0 micron channel
10.3 - 11.3 micron channel
11.5 - 12.5 micron channel
3.55 - 3.95 micron channel
**Optics: Calculations and Trade Studies**

**Analysis:** Vignetting calculations for filter strips indicate possible TDI frame rates as a function of F/\#:

**Design Support:** Design support for the detector sub-assembly: optical path lengths, element spacings, and materials:

**Ghost Images:** calculations to determine guidelines for element spacing:
IR Optical Prescription Data:
F/0.8; Focal length = 55.52 mm; Aperture = 69 mm

A triplet lens design solution:

Spotszie Goal = 46 \mu m; Design Result = 35 \mu m
Encircled energy = 80%

IR Lens Mount (Janos):
Compact Visible and Infrared Radiometer

**IR Imaging radiometer is built around an uncooled microbolometer array detector (UMAD)**

*Technology benefits:*
- No cooling = low power consumption
- No cooling = no thermal radiators
- Focal plane array = Simultaneous 2D imaging
- Focal plane array = compact, lightweight
- Focal plane array = stereo imaging

---

<table>
<thead>
<tr>
<th>Proposed IR Camera</th>
<th>Design Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Imaging</td>
<td>Pushbroom</td>
</tr>
<tr>
<td>Detector</td>
<td>Uncooled microbolometer FPA</td>
</tr>
<tr>
<td>Format</td>
<td>320x240 pixels</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>46.25 um</td>
</tr>
<tr>
<td>Frame Update Rate</td>
<td>60 frames/second</td>
</tr>
<tr>
<td>Telescope</td>
<td>Refractive, F/0.9</td>
</tr>
<tr>
<td>Number of channels</td>
<td>4 (11um, 12umx2, 3.7 um)</td>
</tr>
<tr>
<td>NEDT</td>
<td>0.1 °K</td>
</tr>
</tbody>
</table>

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Focal plane array showing bandpass filters prior to installing germanium package window

IR imaging radiometer showing refractive telescope and electronics imaging module
Compact Infrared and Visible Imaging Radiometer - COVIR

Small Multispectral Infrared and Visible Imaging Radiometer

Cloud and Surface Observations With Combined Spectra and Spatial Imaging

Follow on to ISIR-01 experiment on STS-85 Instrument Incubator Project

- Engineering Model Development

Objective:
- Moderate resolution (1/2km) 5 channel visible and near infrared imaging
- Combined spatial and spectral IR imaging
- Small size and low cost
Flight Mission Instrument Development

Compact Visible and IR Imaging Radiometer
Vertical Imaging Cloud Infrared Imager

CoVIR IIP Instrument
Flight Breadboard
200 km Swath
Mission Proposal Design Study
SIRICE IR Imaging Radiometer

PUSHBROOM SCANNING RADIOMETER
- IR camera stares nadir or at an angle (fore or aft)
- Image is sampled sequentially in each of the 3 spectral channels
- Time Delay and Integration is used to achieve NEDT < 100 mK
- Image spatial resolution ~ 1.5 km/pixel
- Two (possibly three) cameras needed to cover 90° FOV

TECHNICAL CHALLENGES:
- Calibration of the multiple cameras
- Use of TDI requires spacecraft attitude be controlled to align image motion with 1 dimension of detector array

PRACTICAL BENEFITS:
- Natural mode of operation for 2D array
- GSFC has developed two of these systems already
- Most of the technical challenges have been worked out
IRCIR Development

- Three or four cameras based on COVIR design
- Each camera covers a 30 degree swath with a max 22.5 fore-aft angle for stereo
- Basic 1 km resolution with onboard compression and possible stereo processing
- GSFC PI and management
- Cost competition build options:
  - University and GSFC partnership
  - GSFC in house
  - Contracted to industry
IRCIR Characteristics – Signal to Noise Ratio

Current UMAD technology:

\[ \text{NEDT} \sim \frac{200}{\Delta \lambda} (F/#)^2 \text{ mK} \cdot \mu\text{m} \]

For \( \lambda \sim 11 \text{ um} \), 300K scene, F/1

SIRICE Requirements:

- 1 um passband filters
- Three channels 11 um, 12um, 7 um
- NEDT < 100 mK

SIRICE Results:

- Need 3x improvement in SNR
- Include 10 pixels in TDI average (\( \sqrt{10} \sim 3 \))
- Resample single pixel 2x in 0.3 s scan time at 60 fps with <1/10 pixel registration error (SNR increases by \( \sqrt{2} \sim 1.4 \))
IRClIR Global LOE Cloud Imager

- Mirrors rotate ~45 deg off-nadir to view cloud scene
- Mirrors rotate ~270 off-nadir to view blackbody calibration source
- Mirrors rotate ~80 off-nadir to view space for calibration measurement
Infrared Cloud Imaging Radiometer

VIRCIR Concept
1400 km Swath Cloud Retrieval

Front view

4 Calibration blackbodies

Servo-motor, capstan drive combo

4 rotating mirrors

Electronics box

Camera Heads

18.3 cm

14.1 cm

17.3 cm

14.4 cm

24.3 cm

18.4 cm
IRCIR Instrument Concept for Stereo Cloud Track Winds

Science
- IR Cloud Information
- Stereo Cloud Height
- Winds (flying in orbit with NPP)

IRCIR Provides Full Cross-track Coverage using
Four 640 x 480 pixel Uncooled Silicon Micro-bolometer Arrays
IRCIR Located on Dedicated Deck Behind SM4

This view of the instrument is rotated about the S/C axis by 90°
Advanced Technology GOES Imager

- Meets all present GOES Imager Requirements
  - Imaging Radiometric Performance
  - Envelope
  - Mass, Power

- Development Schedule
  - 27 months to flight unit delivery
  - Integration of modern (available) hi-reliability components
Rapid Response IR/Visible GOES Meteorological Imager

**Instrument Characteristics**

- 5 band Step-Staring Imager
  - IFOV: 4 km (IR) /1 km (vis)
  - FOV: 1000 km x 960 km (*Present*)
  - Field of Regard: +/- 20 deg.
  - 4-band IR radiometer (~ 7, 11,12, 13.5 μm with uncooled IR FPAs , 3.9 μm with high temperature(190K) HCT FPA)

**Technology and Programmatic Readiness**

- Technology for all instrument components is sufficiently mature (NASA TRL 7 or higher).
- Preliminary investigation of instrument/spacecraft interface shows no notable concerns.
- Schedule, while aggressive, is consistent with other programs of similar complexity.
NESR for 10.8 μm Channel (Standard LW Window)

- Detector NEP: 3.5 pW/(Hz)^{1/2}
- System Transmission: 50%
- Detector Area: 46x46 μm
- Solid Angle: (f/1.4)
- Noise Bandwidth: 7.5 Hz (4)
- Modulation Frequency: 10 Hz
- Incoherent Sample Summing Improvement Factor: (20)^{1/2}
- Spectral Pass Band: 88 cm^{-1}

**Predicted NESR:** <0.07 mW/str/m^2/cm^{-1}

**Required NESR:** 0.272 mW/str/m^2/cm^{-1} (200 mK NEDT @ 300K)
JEM Attached Payload Modules