2012 Hyperspectral airborne campaign on Etna: multi data acquisition for ASI-PRISMA data simulation and algorithms development

Maria Fabrizia Buongiorno
Istituto Nazionale di Geofisica e Vulcanologia
summary

• PRISMA MISSION OVERVIEW
• ASI-AGI PROJECT
• JUNE 2012 AIRBORNE CAMPAIGN
PRISMA Mission

• Mission Statement:
  “....A pre-operative small Italian hyperspectral mission, aiming to qualify the technology, contribute to develop applications and provide products to institutional and scientific users for environmental observation and risk management ...”

• Mission objectives:
  – In orbit demonstration and qualification of an Italian state-of-the-art hyperspectral/panchromatic camera;
  – Implementation of a pre-operative mission, with demonstrative/technological features;
  – Validation of end-to-end data processing able to develop new applications based on high spectral resolution images for Earth observation and to manage the environmental risks.
  – Capitalization of ASI heritage, considering the Hypseo mission and the Italian-Canadian Joint Hyperspectral Mission (JHM) study
Programme overview

PRISMA = PRercursore IperSpettrale della Missione Applicativa

Mission Objectives:
- Pre-operational and technology demonstrator nature
- Focus on
  - Space qualification of PAN/HYP payload
  - Development and production of PAN/HYP products

Program Highlights:
- National program
- Fully funded by ASI
- Mission includes System, interacting with Target and Users
- System B2/C/D/E1 contract running
- CDR is on-going
- Launch: within 2014
Industrial Organization (Phase B2/C/D/E1)

- **Consortium as “Prime Contractor”:**
  - CGS (Compagnia Generale per lo Spazio)
  - Selex Galileo
  - Telematics Solutions

- **Main Sub-contractors:**
  - Thales Alenia Space Italia
  - Telespazio

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Program: PRISMA  
Event: Third Annual Hyperspectral Imaging Conference  
Topic: PRISMA Mission  
Date: Rome, 15 May 2012
System Architecture

- **Orbit and lifetime:**
  - LEO SSO, 620km, 10.30 LTDN
  - 5 years lifetime

- **System elements:**
  - 1 “small” Satellite
    - Platform
    - Pan/Hyp Payload
    - PDHT
  - Ground Segment
    - MCC/SCC/FDS: Fucino
    - Image Data Handling System: Matera
  - Launch Segment
    - VEGA (baseline)
Mission highlights

- **Coverage:**
  - World-wide
  - Specific Area of interest (AoI)

- **System Capacity:**
  - Acquired data volume:
    - Orbit: >50,000 km²
    - Daily >100,000 km²
  - Daily products generation: 30 HYP/PAN

- **System Latencies (inside AoI):**
  - Re-look time: < 7 days
  - Response time: < 14 days

- **Mission modes:**
  - Primary: User driven
  - Secondary: Data driven (background mission)
Key imaging and payload requirements

- **Swath / FOV:** 30 km / 2.45°
- **Spatial GSD (elementary geom. FoV):**
  - PAN: <5 m (2x6000 pixels)
  - HYP: <30 m (1000x256 pixels)

- **Spectral ranges:**
  - PAN camera: 400-700 nm
  - HYP instrument (contiguous spectrum)
    - VNIR: 400-1010 nm
    - SWIR: 920-2500 nm
- **Spectral resolution:** 10 nm
- **Aperture diameter:** 210mm
- **MTF (@Nyquist frequency)**
  - PAN: > 0.30
  - VNIR: > 0.30
  - SWIR: > 0.20

- **Radiometric Quantization:** 12 bit
- **SNR**
  - PAN: 240:1
  - VNIR: 200:1 (400-1000 nm)
  - SWIR: 200:1 (1000-1750 nm)
  - 400:1 (@1550nm)
  - 100:1 (1950-2350 nm)
  - 200:1 (@2100nm)
- **Absolute radiometric accuracy:** <5%

Program: PRISMA
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Topic: PRISMA Mission
Date: Rome, 15 May 2012
<table>
<thead>
<tr>
<th></th>
<th>Forestry &amp; Agriculture</th>
<th>Environmental monitoring</th>
<th>Urban areas</th>
<th>Geology &amp; volcanic and seismic risks</th>
<th>Glaciers and Snow Surface</th>
<th>Coastal and Inland waters</th>
<th>Biosphere &amp; Climate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Swath width</strong></td>
<td>20-</td>
<td>≥40 km</td>
<td>≥30 km</td>
<td>20-</td>
<td>20-</td>
<td>≥30-</td>
<td>≥30-</td>
</tr>
<tr>
<td><strong>Ground Sampling Distance</strong></td>
<td>20- VIS, SWIR 2,5-5m PAN</td>
<td>20- VNIR, 20- SWIR 1- PAN</td>
<td>0.4-2.5 µm PAN channel</td>
<td>0.4-2.5 µm PAN channel</td>
<td>0.4-2.5 µm PAN channel</td>
<td>0.4-2.5 µm PAN channel</td>
<td>0.4-2.5 µm PAN channel</td>
</tr>
<tr>
<td><strong>Spectral coverage</strong></td>
<td>0.4 - 2.5 µm</td>
<td>0.4 - 2.5 µm</td>
<td>0.4 - 2.5 µm</td>
<td>0.4-2.5 µm</td>
<td>0.4-2.5 µm</td>
<td>0.4-2.5 µm</td>
<td>0.4-2.5 µm</td>
</tr>
<tr>
<td><strong>Spectral resolution</strong> (FWHM)</td>
<td>≤10nm</td>
<td>≤10 nm</td>
<td>10 nm</td>
<td>≤10 nm</td>
<td>10 nm</td>
<td>10 nm</td>
<td>10 nm</td>
</tr>
<tr>
<td><strong>Spectral sampling interval</strong></td>
<td>1 sample per FWHM</td>
<td>5 - 10 nm</td>
<td>1-2 nm</td>
<td>1 sample per FWHM</td>
<td>10 nm</td>
<td>5 nm</td>
<td>10 nm</td>
</tr>
<tr>
<td><strong>SNR@30%refl; 30°SZA:</strong></td>
<td><strong>WNIR SWIR</strong></td>
<td><strong>WNIR SWIR</strong></td>
<td><strong>WNIR SWIR</strong></td>
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<tr>
<td><strong>SWIR</strong></td>
<td>600:1 450:1</td>
<td>600:1 450:1</td>
<td>800:1 500:1</td>
<td>800:1 500:1</td>
<td>500:1</td>
<td>1000:1</td>
<td>600:1</td>
</tr>
<tr>
<td><strong>Radiometric Quantization</strong></td>
<td>12-16 bit</td>
<td>≥12 bit</td>
<td>12-16 bit</td>
<td>12-16 bit</td>
<td>&gt;12 bit</td>
<td>14-16 bit</td>
<td>12-16 bit</td>
</tr>
<tr>
<td><strong>Radiometric calibration accuracy</strong></td>
<td>≤5% goal 3%</td>
<td>≤5%</td>
<td>&lt;0.01 µWcm²nm⁻¹sr⁻¹</td>
<td>≤5% goal 1%</td>
<td>&lt;5%</td>
<td>&lt;0.01 µWcm²nm⁻¹sr⁻¹</td>
<td>≤5%</td>
</tr>
<tr>
<td><strong>Spectral calibration accuracy</strong></td>
<td>0.1 nm</td>
<td>0.1 nm</td>
<td>0.1 nm</td>
<td>0.3 nm</td>
<td>0.3 nm</td>
<td>0.3 nm</td>
<td>0.1 nm</td>
</tr>
<tr>
<td><strong>Equator crossing time day</strong></td>
<td>9:30 – 11:00 local time</td>
<td>10-12 local time</td>
<td>10 local time</td>
<td>9:30 - 10:30 local time 11-12 local time</td>
<td>10:00 – 11:00 local time</td>
<td>10:00 – 11:00 local time</td>
<td></td>
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<tr>
<td><strong>Night acquisition time</strong></td>
<td></td>
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</tr>
</tbody>
</table>
National competition for 5 scientific projects
Duration: 4 years
2 main tasks:
- Research on specific theme referring to the ASI list of applications using similar-PRISMA data and, after launch, PRISMA data
- Scientific support to ASI PRISMA project team
Identification of 5 Principal Investigators (PIs) in a Scientific Advisory Team
Common Kick Off: 14/04/2011
<table>
<thead>
<tr>
<th>TITLE</th>
<th>Name of the institute</th>
<th>Institute Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of algorithms and products for applications in agriculture and land monitoring to support the PRISMA mission (SAP 4 PRISMA)</td>
<td>Istituto di Metodologie per l’Analisi Ambientale INAA CNR</td>
<td>Vincenzo Cuomo</td>
</tr>
<tr>
<td>Singergistic use of PRISMA products with high resolution meteo-chemistry simulations and their validation from ground and satellites (PRIMES)</td>
<td>CETEMPS - Univ. de L’Aquila</td>
<td>Guido Visconti</td>
</tr>
<tr>
<td>Hyperspectral systems analysis for integrated geophysical applications (ASI-AGI)</td>
<td>Istituto Nazionale di Geofisica e Vulcanologia (INGV)</td>
<td>Fabrizia Buongiomo</td>
</tr>
<tr>
<td>Advanced methodologies for analysis, integration and optimization of PRISMA level 1 and 2 products - OPTIMA -</td>
<td>Istituto di Fisica Applicata Nello Carrara (IFAC -CN)</td>
<td>Ivan Pippi</td>
</tr>
<tr>
<td>Coasts and Lake Assessment and Monitoring by PRISMA HYperspectral Mission (CLAM PHYM)</td>
<td>Institute of Marine Sciences (ISMAR - CNR)</td>
<td>Luigi Alberotanza</td>
</tr>
</tbody>
</table>
For any further information on the PRISMA mission, please contact the ASI Program Manager

roberto.formaro@asi.it

For any further information on the scientific studies please contact

cristina.ananasso@asi.it
ASI-AGI

Analisi Sistemi Iperspettrali per le Applicazioni Geofisiche Integrate
Project Structure
ASI-AGI PROJECT ACTIVITY SCHEME

- Common utilities
- Information extraction modules
- CAL/VAL Activities and data simulation
- Flight campaigns.
- Calibration sites
- PRISMA data Simulator

- Atmospheric correction
- Pan Sharpening
- Topographic Correction
- Superficial Classification
- Lava Thermal analysis
- Volcanic emitted gases analysis
- Fire Spectral Characterization
PRISMA SIMULATOR

- Module developed in IDL which will take in input the PRISMA instrument response functions, S/N, view geometry furnished by ASI

- to calculate
  - simulated radiance
  - Simulated path radiance
  - Simulated Spectral and spatial response of the instrument
  - Simulated N/S
Prisma Radiance Simulator

Surface characteristics → 1 → Modtran → 2 → Acquisition characteristics

Surface characteristics → 4 → Response function (Hyperion/PRISMA)

Response function (Hyperion/PRISMA) → 3 → TOA → Atmospheric characteristics
PHASE 1

MODTRAN has been used to model the sensor and atmospheric parameter for each pixel the considered PRISMA sub set of 10000 pixles

- Surface temperature 290 K (circa 17° C)
- Mid latitude Summer (Latitude 45° Nord)
- Satellite altitude 700 Km
- Albedo: Riflettance map calculated by means of Hyperion image acquired on Mt. Etna
- Spectral Range: 0.842-0.844
PHASE 2

On beginning of 2012 the industrial team started the calibration measurements of system optical components in laboratory

In order to improve the simulation products we introduced the information provided by the industrial team

• Prisma laboratory simulated response function.
• Simulated NdL of the instrument
To make the modeling more complex we have introduced the DEM information and temperature map of the surface for the select day.
Topographic information and surface geometry informations as "aspect" e "slope" to calculate the contribute from adjacent pixels.
Phase 2 results

Radianza reale

Radianza simulata

230x380 pixels
AIRBORNE CAMPAIGN ON ETNA
JUNE 22-28 2012

Participants
Stefania Amici(1), Laura Colini(1), Fawzi Doumaz(1), Valerio Lombardo(1), Francesco Mazzarini(1), Massimo Musacchio(1), Malvina Silvestri(1), Claudia Spinetti(1), Massimiliano Favalli(1), Ilaria Isola(1), Marco Neri(1), Salvo Giammanco(1), Tommaso Caltabiano(1), Giuseppe Salerno(1), Alessandro La Spina(1) Giuseppe Puglisi(1), Sergio Teggi(2), Valentina Sarli(3), Giovanni Mancini (4), Paolo Cafaro(4), Salvatore D'Andrea(4), Gabriele Curci(5) and Cristina Ananasso(6).

1 Istituto Nazionale di Geofisica e Vulcanologia
2 Università di Modena e Reggio Emilia
3 Centro di Geomorfologia Integrata dell’Area del Mediterraneo (CGIAM)
4 Corpo Capitanerie di Porto
5 Università degli Studi dell'Aquila CTEMS
6 Agenzia Spaziale Italiana
The CAL/VAL activities are based on 4 specific goals

1. Organize an airborne campaign on MT. Etna which is the main test site for ASI-AGI PROJECT and acquire a suitable hyperspectral data set to simulate the PRISMA data and test the developed algorithms,

2. Get possibly contemporaneous Hyperion and ASTER data to use the data set also to simulate HyspIRI data

3. Organize a contemporary in situ campaign to acquire surface and atmospheric parameters and validate the airborne data and complete a spectral library for Mt. Etna different lava flows.

4. Define a vicarious test site in North Africa in the Algerian desert year
Etna airborne campaign 2012
<table>
<thead>
<tr>
<th>Date</th>
<th>GROUND ACTIVITIES</th>
<th>AIRBORNE AND SPACEBORNE ACQUISITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.06.2012</td>
<td>MILO</td>
<td>Hyperion acquisition</td>
</tr>
<tr>
<td></td>
<td>Logistic activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ground instrument TEST and fieldspec measurements</td>
<td></td>
</tr>
<tr>
<td>24.06.2012</td>
<td>BRONTE</td>
<td>TEST FLIGHT BY CGIAM</td>
</tr>
<tr>
<td></td>
<td>Start ground measurements FieldSpec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ETNA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Set up sun photometer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paternò</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Site ispection</td>
<td></td>
</tr>
<tr>
<td>25.06.2012</td>
<td>ETNA</td>
<td>TERRA-ASTER</td>
</tr>
<tr>
<td></td>
<td>Thermal termica, Unilogger FTIR (Pian del Lago)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FieldSpec (Strada Forestale ed Etna Nord)</td>
<td></td>
</tr>
<tr>
<td>26.06.2012</td>
<td>PATERNO’</td>
<td>EO1- HYPERION</td>
</tr>
<tr>
<td></td>
<td>FieldSpec, Unilogger Laser Scanning</td>
<td></td>
</tr>
<tr>
<td>27.06.2012</td>
<td>FORNAZZE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FieldSpec</td>
<td></td>
</tr>
</tbody>
</table>
AIRBORNE SYSTEM

CGIAM PARTNER WAS IN CHARGE OF THE AIRBORNE SYSTEM AND FLIGHTS
NAVIGATION AND RECORDING SYSTEM

1. **CCNS** – (Computer Controlled Navigation System) finalizzato al controllo del volo e dei sensori.

2. **AEROcontrol** System for positioning, it integrates GPS data at 24 channels at 2Hz and data from **IMU-IId** (Inertial Measurement Unit) a 256 Hz based on gyro in fiber optics fibra ottica. The computer also ensure the registration on data card of raw data from **IMU** and **GPS**
SENSOR SYSTEM

- HYPERSPECTRAL CAMERA
- LIDAR
- THERMAL CAMERA
- OPTICAL CAMERA
- NAVIGATION AND REGISTRATION SYSTEM
- SYSTEM BOARD
HYPER SPECTRAL CAMERA

PUSH–BROOM system with 2 spectrometer in the VNIR–SWIR range, the spectrometer were purchased from SPECIM

The systems case perimits to operate the cameras also from the ground

<table>
<thead>
<tr>
<th>Spectrometer Name</th>
<th>VNIR</th>
<th>SWIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>ImSpector V10E / Specim</td>
<td>ImSpector N25E / Specim</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>400-1000 nm</td>
<td>1000-2500 nm</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>2.8 nm</td>
<td>10 nm</td>
</tr>
<tr>
<td>Spectral Sampling</td>
<td>1.2 nm</td>
<td>6.3 nm</td>
</tr>
<tr>
<td>Spectral bands</td>
<td>504</td>
<td>239</td>
</tr>
<tr>
<td>Spatial pixels</td>
<td>1024</td>
<td>320</td>
</tr>
<tr>
<td>Digital resolution</td>
<td>12 bit</td>
<td>14 bit</td>
</tr>
<tr>
<td>FOV</td>
<td>68.64°</td>
<td>36°</td>
</tr>
<tr>
<td>Focal length</td>
<td>9 mm</td>
<td>15 mm</td>
</tr>
</tbody>
</table>
The LiDAR (Riegl LMS-Q560) permits the Full Waveform Analysis.

The laser beam (Eye Safety Class) works in the near IR frequency range.
THERMAL CAMERA  DigiTHERM

CARATTERISTICHE CAMERA TERMICA

<table>
<thead>
<tr>
<th>Caratteristica</th>
<th>Valore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range Spettrale</td>
<td>7.5 - 14 µm</td>
</tr>
<tr>
<td>Dimensione del pixel</td>
<td>25 µm</td>
</tr>
<tr>
<td>Dimensione della testa del sensore</td>
<td>16 X 12 mm</td>
</tr>
<tr>
<td>Range di Temperatura</td>
<td>-40° - 120° C</td>
</tr>
<tr>
<td>Intervallo di temperatura per l'operatività</td>
<td>-15  +50°C</td>
</tr>
</tbody>
</table>

METODOLOGIA ACQUISIZIONE

<table>
<thead>
<tr>
<th>Caratteristica</th>
<th>Valore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microbolometro non raffreddato FPA</td>
<td>640 X 480 pixel</td>
</tr>
<tr>
<td>(Focal Plane Array)</td>
<td></td>
</tr>
<tr>
<td>Massima Frequenza di scatto</td>
<td>6 Hz</td>
</tr>
<tr>
<td>Range dinamico</td>
<td>16 bit</td>
</tr>
</tbody>
</table>

PRECISIONE E RISOLUZIONE

<table>
<thead>
<tr>
<th>Caratteristica</th>
<th>Valore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuratezza di misura</td>
<td>+/- 1.5K(0°...100°C)</td>
</tr>
<tr>
<td></td>
<td>Altrimenti +/- 2K</td>
</tr>
</tbody>
</table>

DigiTHERM è un sistema professionale di camera termica aereotrasportato.
• METRIC CAMERA DigiCAM H-39

- Resolution: 39 Megapixel
- Storage: 2 disk 100 Gbyte
- Acquisition interval: 1.9 sec
- Filters: Color (VIS) and Color-infrared (CIR)
Sistema aereo di acquisizione dati

- System board

The systems are mounted on alluminiun plate with dampers to avoid system vibration.
Calibration flight

- 23.06.2012 a calibration flight to test all the system functionality on the aircraft was performed in Perugia
- definition of the "boresight" angles for each sensore
- sensor tests

Flight parameters
Quota: 700 m –1400 m agl
Time: 10.40 –11.15 locale
N. Flight lines 8
Directions W–E, E–W, N–S, S–N
Flight test on Mt. Etna

- On 24.06.2012 the system performed a test flight on Etna to verify
  - Acquisition parameters (e.g. time integration, frame rate, flight velocity)
  - Operational condition at the required flight altitude (4500–5000 m)

- Flights parameters
  Quota: 4500 m sml
  Time: 9 – 11 local
  N flights 3
  Flight dir NW–SE, SW–NE
Volo su Mt.Etna

- 25.06.2012 flight campaign on Etna
  - Hyperspectral data
  - Thermal camera
  - Optical camera

Flight parameters
Quota: 4500 m sml
time: 9 – 11 local
N flights lines; 8
Flight direction NW–SE, SW–NE, SE–NW

Strisciate acquisite sull’Etna il giorno 25.06.2012.
In celeste le strisciate nello SWIR, in fucsia le strisciate nel VNIR, in bianco le linee di volo.
Flights on Paternò area

- 26.06.2012 flight campaign on Paternò:
  - hyperspectral data
  - Lidar data
  - thermal camera
  - optical camera

- flight parameters on Paternò
  Quota: 1000 m agl
  Time: 9.15 – 10.15 local
  N flights lines: 10
  Direction SE–NW, NW–SE

Strisciate acquisite su Paternò il giorno 26.06.2012.
In celeste le strisciate nello SWIR, in fucsia le strisciate nel VNIR, in bianco le linee di volo.
SATELLITE DATA ACQUISITION

Thanks to the collaboration and support of NASA-GODDARD and NASA-JET PROPULSION LABORATORY

HYPERION and ASTER have been acquired during the flights over Etna and Paternò area
Acquired Satellite Data

Aster 25 Giugno 2012 – 09:53 UTC

Hyperion 23-26-28 Giugno 2012
FIELD CAMPAIGN
The field campaign has been dedicated to acquire surface spectral characteristics, texture, temperature, emissivity and local atmospheric parameters.

The data will be use to validate both airbone and spaceborne data.

Instrument used:

- Fieldspec
- ground Laser Scanning
- GPS
- thermal camera
- sun photometer
- Unilogger to record continuous meteo station data and ground temperature
- Micro-FTIR
Measurement sites

- rock spectra related to different Etna lava flows
- Ground laser scanner to analyse the surface texture

I dati sono divisi per strumentazione (FieldSpec o Laser 3D) e per periodo di acquisizione. I dati sono proiettati sulla nuova cartografia geologica alla scala 1:50000 dell’Etna.
Fieldspec measurements
Laser Scanning
Lava optical photo and foto 3D models derived from Laser 3D and from the system "structure from motion"
THERMAL CAMERA

Thermoteknix System Ldt VisIR 640
The collected images have been acquired from 9.40 AM local time up to 12.26 AM local time.

Snow deposits covered by ash.
The sun photometer and l’unilogger have been used to acquire information on the atmosphere.
MicroFTIR
PRELIMINARY DATA ANALYSIS

HYPERSPECTRAL DATA:
DN calibration to radiance
Preliminary geocoding

Strip 1 su M. Etna – Composizione CIR (814.66nm 694.03nm 574.20nm)
Spectra inside the plume

Spectra on the sulfur deposits
Spectra inside the plume

Spectra on the sulfur deposits
THERMAL CAMERA:

Termogramma su M.Etna
OPTICAL CAMPERA

- radiometric correction
- geometric correction
Airborne Lidar Data

- Conversion of impulse
- Geocoding of acquired points
CONCLUSION

In the coming months both ground measurements analysis and airborne data calibration will continue in order to prepare suitable data set for the algorithms developed in the ASI-AGI project.

Atmospheric corrections will be applied to selected flight lines.

The satellite data will be also processed to retrieve reflectance and emissivity.

Ground data will be prepared to create a spectral library for Etna lava flows end members.

A complete campaign report will be published in english in the next months.

We are available to collaborate with HyspIRI scientists interested to the data set.
WE ARE VERY THANKFUL TO

ALL THE ASI-AGI CAMPAIGN TEAM and INGV COLLEAGUES FROM CATANIA WHO HELP US IN ALL THE MEASUREMENTS ON ETNA and PATERNO

ASI PRISMA TEAM

THE NASA-GODDARD and JET PROPULSION LABORATORY FOR CONSTANT SUPPORT IN ACQUIRING HYPERION AND ASTER DATA