HIRDLS Delta Pre-Ship Review

21 November 2002

Oxford University
Welcome & Introductions

Chris Hepplewhite
## Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Presenter</th>
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<tbody>
<tr>
<td>0800-0810</td>
<td>Welcome to Oxford</td>
<td>C. Hepplewhite</td>
</tr>
<tr>
<td>0810-0820</td>
<td>Team Introduction and Review Objectives</td>
<td>C. Hepplewhite</td>
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<td>0820-0830</td>
<td>GSFC/RAL Systems Review Team Introduction</td>
<td>C. Mutlow &amp; D. Dillman</td>
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<td>0830-0900</td>
<td>Introduction to Aura Mission and HIRDLS Instrument</td>
<td>J. Gille</td>
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<td>0900-0915</td>
<td>State of the Instrument</td>
<td>G. Jackson</td>
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<td>0915-0930</td>
<td>Issues</td>
<td>G. Jackson</td>
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<td>0930-1000</td>
<td>Calibration Test Configuration Overview</td>
<td>C. Hepplewhite</td>
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<td>1000-1030</td>
<td>Calibration Objectives</td>
<td>C. Palmer</td>
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<td>1030-1045</td>
<td>Coffee Break</td>
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<td>1045-1530</td>
<td>Calibration Accomplishments</td>
<td>C. Palmer/T. Eden/D. Peters</td>
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<td>1230-1300</td>
<td>Lunch</td>
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<td>1300-1530</td>
<td>Spectral Calibration</td>
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<td></td>
<td>In-Band</td>
<td>C. Palmer</td>
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<tr>
<td></td>
<td>Out-of-Band</td>
<td>T. Eden</td>
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<td></td>
<td>Field-of-View Calibration</td>
<td>J. Barnett/C. Palmer</td>
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<tr>
<td>1530-1545</td>
<td>On Orbit Calibration Plans</td>
<td>C. Palmer/J. Moorhouse</td>
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<td>1545-1600</td>
<td>Tea</td>
<td>J. Barnett/J. Gille</td>
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<td>1600-1630</td>
<td>Shipment and Integration with Observatory</td>
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<td>Transport Plan</td>
<td>P. Roycraft</td>
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<td>1630-1645</td>
<td>Past Review Open Requests-For-Action Status</td>
<td>G. Jackson</td>
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<td>1646-1700</td>
<td>PIs' Assessment / Closure</td>
<td>J. Gille / C. Hepplewhite</td>
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<tr>
<td>1700-1745</td>
<td>Break and Review Team Caucus</td>
<td>J. Gille</td>
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<tr>
<td>1745-1830</td>
<td>RFA Summary &amp; Review Team Comments</td>
<td>C. Mutlow &amp; D. Dillman</td>
</tr>
<tr>
<td>1830</td>
<td>Adjourn</td>
<td></td>
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</tbody>
</table>
Welcome

• Agenda
  — Timetable
  — Logistics
• List of attendees (distribute a form for contact details) and standup!
• Forms for questions, RFA, Comments
• Review Objectives
Review Objectives

- Present the Instrument Configuration
- Present pre-launch calibration accomplishments to date
- Identify the pre-launch calibration testing and analyses still to occur
- Present the transportation plan to get the HIRDLS instrument from Oxford University to TRW
- Reach consensus that pre-launch calibration objectives will be met and that the HIRDLS Team can break configuration to go to the observatory
GSFC/RAL Systems Review
Team Introduction

C.T. Mutlow/Dennis Dillman
Introduction to Aura Mission and HIRDLS Instrument

John Gille
Overarching Scientific Questions Addressed by Aura

• Is the ozone layer recovering?
  – Requires measurements of ozone and ozone destroying radicals from the chlorine, nitrogen and hydrogen families
  – Determine whether the evolution of ozone, in time and space, is as expected from scientific models

• How is the Earth’s climate changing?
  – What is the distribution of greenhouse gases, water vapor and ozone, and aerosols, in the upper troposphere and lower stratosphere?
  – What are the mechanisms by which these distributions are maintained?
  – What are the mechanisms by which these and other tracers are exchanged between the troposphere and stratosphere?

• Is air quality getting worse?
  – What are the distributions of ozone, reactive nitrogen and hydrogen species, and aerosols in the troposphere?
HIRDLS’ Region of Emphasis:
The Upper Troposphere/Lower Stratosphere

Polar vortex

Tropical barrier

over world

middle world

under world

Wave-driven extratropical "pump"

Large-scale subsidence

Some cumulonimbus clouds penetrate stratosphere

Large-scale ascent

Exchange across tropopause facilitated by anticyclones, cut-off cyclones and tropopause folds

tropopause
HIRDLS Scientific Objectives

• Understand stratosphere-troposphere exchange of radiatively and chemically active constituents (including aerosols) down to small spatial scales

• Understand chemical processing, transports and mixing in the upper troposphere/lowest stratosphere/lower overworld

• Understand budgets of quantities (momentum, energy, heat and potential vorticity) in the middle atmosphere that control stratosphere-troposphere exchange

• Determine upper tropospheric composition (with high vertical resolution)

• Provide data to improve and validate small scales in models

• Measure global distributions of aerosols and PSC’s and interannual variations
Major HIRDLS Emphases

• Small scale dynamics and transports
  — Troposphere – stratosphere exchange
  — Polar vortex filamentation
  — Tropical barrier leakage

• Upper troposphere – lower stratosphere chemistry
  — O$_3$, H$_2$O, CFC$_{11}$, CFC$_{12}$, HNO$_3$, CH$_4$, N$_2$O

• Aerosol amounts, distributions and properties

• Trends and changes
  — Trends of 10 radiativity and chemically active species, T, PSCs
  — Continuation of LIMS, SAMS, UARS

• Gravity wave distributions

• Sources and distributions of gravity waves, and their roles in atmospheric dynamics
Summary of Measurement Requirements

**Temperature**

- **<50 km**
  - 0.4 K precision
  - 1 K absolute

- **>50 km**
  - 1 K precision
  - 2 K absolute

**Constituents**

- O$_3$, H$_2$O, CH$_4$, H$_2$O, HNO$_3$, NO$_2$, N$_2$O$_5$
- ClONO$_2$, CF$_2$Cl$_2$, CFCl$_3$, Aerosol

- 1-5% precision
- 5-10% absolute

**Geopotential height gradient**

- 20 metres/500 km (vertical/horizontal)
- Equivalent 60°N geostrophic wind (3m s$^{-1}$)

**Coverage:**

- **Horizontal** - global 90°S to 90°N (must include polar night)
- **Vertical** - upper troposphere to mesopause (80-80 km)
- **Temporal** - long-term, continuous (5 years unbroken)

**Resolution:**

- **Horizontal** - profile spacing of 5° latitude x 5° longitude (approx 500 km)
- **Vertical** - 1-1.25 km
- **Temporal** - complete field in 12 hours
LIMB Scanning Geometry for Multiple Azimuths

Location of Vertical Scans

Present Swath

Previous Swath

5° “latitude”

5° “longitude”

Line of Sight From Spacecraft
HIRDLS Sampling of Ozone Field Showing High Horizontal Resolution Coverage
Spectral Locations of the HIRDLS Channels

• Positions set by locations of atmospheric absorption bands

• Observing UT/LS requires channels in low absorption wings of bands

• Observing aerosols requires channels with low gaseous absorption
Critical Parameters For HIRDLS

For any spectral channel,

\[ N(h) = A \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} B[T(X), v] \frac{\partial \tau(v, h + \phi, x, \mu(x))}{\partial x} S(v) F(\phi) d\phi d\phi d\tau \]

Where:
- \( N \) = measured radiance
- \( h \) = tangent height of measurement
- \( A \) = calibration constant
- \( S \) = spectral response function
- \( F(\phi) \) = field of view function
- \( B \) = Planck black body function
- \( \nu \) = frequency
- \( \tau \) = atmospheric transmittance
- \( T \) = temperature
- \( \mu \) = mixing ratio

To retrieve the temperature:
known \( \mu \) of CO\(_2\) \( \rightarrow \) known \( \tau \) \( \rightarrow \) iteratively solve for \( B \) \( \rightarrow \) consistent \( T \) (pressure)

To retrieve the mixing ratio of a particular gas:
known \( T \) \( \rightarrow \) known \( B \) \( \rightarrow \) iteratively solve for \( \tau \) consistent \( T \) (pressure)
Critical Measurement Considerations

Channel 3 (CO₂, optically thick)

HIRDLS information extracted from Limb Radiance Profile N(h)

Crucial quantities that affect results are:
- Uncertainty in radiance
  - Radiometric accuracy
  - Radiometric noise
- Out of field radiation
- Field of View (FOV) function & FOV MAP, (as function of AZ angle)
- Relative Vertical Position
  - Encoder accuracy
  - Encoder precision
  - Gyro accuracy
  - Gyro precision
# Impact of Science Requirements on Instrument Requirements

<table>
<thead>
<tr>
<th>Science Requirements</th>
<th>Instrument Requirement</th>
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<tbody>
<tr>
<td>Temperature</td>
<td>Radiometric accuracy</td>
</tr>
<tr>
<td>&amp; Constituent Accuracy</td>
<td>0.5% CH 2-5 (T)</td>
</tr>
<tr>
<td></td>
<td>1.0% CH 1, 6-21 (constituents)</td>
</tr>
<tr>
<td>Mean sample spacing accuracy</td>
<td>(0.25%) 0.85 – 2.5 arcsec/sec</td>
</tr>
<tr>
<td>Temperature</td>
<td>Radiometric noise</td>
</tr>
<tr>
<td>&amp; Constituent Precision</td>
<td>1.1 – 12x10^-4 w/m2 sr</td>
</tr>
<tr>
<td></td>
<td>(channel dependent)</td>
</tr>
<tr>
<td></td>
<td>Random LOS pointing error in signal bandwidth (0-15 Hz)</td>
</tr>
<tr>
<td></td>
<td>&lt;1 arcsec</td>
</tr>
<tr>
<td></td>
<td>Random LOS jitter error (&gt;36 Hz)</td>
</tr>
<tr>
<td></td>
<td>&lt;7 (TBV) arcsec RMS</td>
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</table>
Impact of Coverage and Resolution Requirements

Science Requirements

- Global day-night coverage
- Determine temperature, many trace species
- 1 km vertical resolution
- Limb viewing and oversampling
- Multiple scan rates
- Longitudinal resolution <orbital spacing
- 5° Longitude x 5° Latitude

Instrument Requirements

- Measure atmospheric emission
- Infrared emission, limb viewing
- Limb viewing, narrow FOV oversampling, low noise
- Continuous limb scanning. Precise knowledge of relative LOS directions. (Slow vertical scans in research mode)
- Programmable scan rate
- Limb scans at multiple azimuths
- ∴ 2 axis scanner
- 6 vertical scans in 66 sec
## HIRDLS Instrument Basic Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>ORBIT</strong></td>
<td>705 km, 1:45 ±15 PM ascending (goal: formation fly with Aqua, 1:38 ±5 PM)</td>
</tr>
<tr>
<td><strong>SWATH</strong></td>
<td>64° (az field of regard), 66 sec typical</td>
</tr>
<tr>
<td><strong>SCANNING</strong></td>
<td>5.25° (el limb scan range), 10 sec typical, open loop</td>
</tr>
<tr>
<td><strong>DETECTOR IFOV</strong></td>
<td>1 km (el) x 10 km (az) at limb, @ 3000 km range</td>
</tr>
<tr>
<td><strong>DWELL TIME</strong></td>
<td>60 msec (typical global mode)</td>
</tr>
<tr>
<td><strong>OPTICS</strong></td>
<td>Scan Mirror, 2-mirror unobscured telescope, cascaded stops, refractive relay, 160 mm aperture, EFL 242 ±4 mm, warm &amp; cold filters</td>
</tr>
<tr>
<td><strong>SPECTRAL</strong></td>
<td>21 discrete channels in range 6 to 18 µm, bandpass filters, 4 CO₂ temperature sounding channels, 3 aerosol channels</td>
</tr>
<tr>
<td><strong>RADIOMETRIC</strong></td>
<td>0 - ~300 K radiance range, signal/noise ~ 3 x 10⁴ in 7.5 Hz bandwidth</td>
</tr>
<tr>
<td><strong>DETECTORS</strong></td>
<td>HgCdTe photoconductor, AC coupled</td>
</tr>
<tr>
<td><strong>DETECTOR COOLING</strong></td>
<td>Sterling refrigerator, 60-65 K, nominal setpoint = 62 K</td>
</tr>
<tr>
<td><strong>CALIBRATION</strong></td>
<td>Laboratory radiometric, spatial, &amp; spectral; on-board 2-point radiometric calibration every ~ 66 sec</td>
</tr>
<tr>
<td><strong>DATA RATE</strong></td>
<td>72 kbps (peak &amp; avg), 500 Hz chopped detector signals digitally filtered to 83 Hz telemetry rate each channel plus gyro &amp; encoder pointing data</td>
</tr>
<tr>
<td><strong>SIZE, MASS, POWER</strong></td>
<td>1.5 m x 1.2 m x 1.3 m (XYZ), 188 kg., 262 W (2-orbit avg)</td>
</tr>
<tr>
<td><strong>MISSION LIFE</strong></td>
<td>5 years (6 years goal)</td>
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</table>
Optical Schematic

- Space View Port
- Albedo Shield
- Space View Field Stop
- Secondary Mirror
- Telescope Subsystem
- Structural Thermal Subsystem
- Space View Aperture Stop
- Space View Relay Mirror
- Intermediate Lyot Stop
- Field Stop #1
- Chopper
- Chopper Mechanical Unit
- Field Stop #2
- Warm Filter Assembly
- Ge Lens #1
- Fold
- System Aperture Stop
- Ge Lens #2
- Primary Mirror
- Cold Filter Assembly
- Primary Diffraction Baffle (PDB)
- "Hot Dog" Aperture
- DSS
- In-flight Calibrator Black Body
- Calibrator Mirror
- Sunshield Door
- Sunshield Door Aperture
- Fixed Sunshade

HIRDLS Delta PSR – Oxford University
21 November 2002
Aura Mission.
HIRDLS Photons To Data

HIRDLS Instrument

Telescope S/S

Shaft Encoders

TEU

LOS Data

Chopper Reference Signal

LOD Data

Radiometric Data

• Filtering
• A/D Conv.

• Data Sync.
• Packetization

SPU

IPU

Instrument Processor S/S

DSS

• Cold Spectral Filters

CSS

• Warm Spectral Filters
• Chopper

Imaging Optics

Scan Mirror

• Limb
• Space View

Limb

Space View

IFC
Blackbody

Chopper / Space Ref. View

Chopper / Space Ref. View

Internal to Instrument

Space View Aperture

Instrument Main Aperture
HIRDLS Instrument is Comprised of 9 Subsystems
Instrument Parameters in Overall Transfer Function

Radiative transfer equation

For each spectral channel:

\[ N(h) = G \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} B[T(X), \nu] \frac{\partial\tau(\nu, h + \phi, x, \mu(x))}{\partial x} S(\nu)F(\phi) d\nu d\phi dx \]

Where:
- \( N \) = measured radiance
- \( h \) = tangent height of measurement
- \( G \) = radiance gain constant
- \( S \) = spectral response function
- \( F(\phi) \) = field of view function
- \( B \) = Planck black body function
- \( \nu \) = frequency
- \( \tau \) = atmospheric transmittance
- \( T \) = temperature
- \( \mu \) = mixing ratio

\( h \) - requires relative pointing calibration (encoder, gyro)
\( G, S \) and \( F \) are calibration parameters
\( S \) and \( F \) are measured before launch
\( A \) is determined in flight, but relationship to international standards and non linearity measured before launch

HIRDLS Delta PSR – Oxford University
21 November 2002
State of the Instrument
Glenn Jackson
Accumulated Operating Time To Date

• Currently in chamber in Nominal Orbit Environment
  – Flight configuration except for
    • Heater Diode Unit not bonded
    • Testing optic installed
    • MLI is not final configuration

• Operating Time To Date (LM and Oxford Operations)
  – A-Side: 316 Hours
  – B-Side: 712 Hours

• No anomalies to date have chronically interfered with calibration.
Configuration Changes
Since 31 July PSR

• All Instrument Hardware Configuration Changes
  – Heater Diode Unit (HDU) wired but not secured for flight [FOR FLIGHT]
  – Test-only temperature sensors wiring modified [FOR GRND TEST ONLY]
  – MLI taping configuration change [FOR GRND TEST ONLY]
  – Non-flight alignment mirror installed (“Whitney mirror”) [FOR GRND TEST ONLY]

• Flight Software Configuration Changes
  – Temperature sensor noise reduction added
  – Heater duty cycle control modification (AR 011)
  – Initialize IFC power state & update IFC over-temp fault mgmt (AR 001)
  – No service of GSS interface when GSS decrementer is timing source
  – Reduce the HWA default over-temp value to 110º C (AR 004)
Instrument Issues
Old and New
Glenn Jackson
## HIRDLS Instrument Issues

<table>
<thead>
<tr>
<th>Item</th>
<th>Mission Impact</th>
<th>Likelihood</th>
<th>Description</th>
<th>AR or DR #</th>
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<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>Increased SMA Azimuth Stiction</td>
<td>AC2158</td>
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<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>CCU Caging Circuit Relay</td>
<td>AD7186</td>
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<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>CCU Reset</td>
<td>AD7185</td>
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<td>4</td>
<td>1</td>
<td>1</td>
<td>Chopper Speed Fluctuation</td>
<td>AB5509</td>
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<td>5</td>
<td>1</td>
<td>1</td>
<td>Uncommanded IPU Reset</td>
<td>AB7707</td>
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<td>6</td>
<td>2</td>
<td>1</td>
<td>PCU Current Monitor Failure</td>
<td>AD7173</td>
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<td>7</td>
<td>2</td>
<td>1</td>
<td>PCU Transistor Failure</td>
<td>AD7188</td>
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<td>8</td>
<td>2</td>
<td>1</td>
<td>Current Trip Transistor Failure</td>
<td>AD7187</td>
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<td>9</td>
<td>1</td>
<td>3</td>
<td>D0 Temp Sensor Anomaly</td>
<td>AD7147</td>
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<td>10</td>
<td>1</td>
<td>1</td>
<td>CMU Contam</td>
<td>AD7455</td>
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<tr>
<td>11</td>
<td>1</td>
<td>1</td>
<td>Excess Noise on Temp Sensors</td>
<td>AD7248</td>
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<td>12</td>
<td>1</td>
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<td>Heater Design Deficiency</td>
<td>T-V TR</td>
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<td>13</td>
<td>3</td>
<td>2</td>
<td>IFC Telemetry Jumps</td>
<td>AR002</td>
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<td>14</td>
<td>1</td>
<td>1</td>
<td>Jitter in Cal</td>
<td>AR009</td>
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<td>15</td>
<td>1</td>
<td>1</td>
<td>GSE QB shutdown</td>
<td>AR014</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>1</td>
<td>RTN crashes</td>
<td>AR016</td>
</tr>
<tr>
<td>17</td>
<td>2</td>
<td>2</td>
<td>Loss of 1553/Current Spike</td>
<td>AR017</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>1</td>
<td>GSE QB shutdown with power fluctuation</td>
<td>AR014</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>1</td>
<td>RTN freezes</td>
<td>AR016</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>2</td>
<td>CS02 susceptibility</td>
<td>EMI/EMC TR</td>
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<tr>
<td>21</td>
<td>1</td>
<td>1</td>
<td>Power Converter Oscillations</td>
<td>AD6418</td>
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</tbody>
</table>

1=low, 2=medium, 3=high

UVFs from System & Sub-system I&T
HIRDLS Instrument Issue Spectrum (grouped by current status)

- Red Box: Mission Critical Issue
- Yellow Region: Mission Concern Issue

1. 1
2. 6, 7, 8
3. 2, 3, 4, 5, 10, 11, 12, 14, 15, 16, 18, 19, 21
4. 13
5. 17, 20
6. 9

Increasing Mission Impact

Increasing Likelihood To Occur
• D0 Cryo-diode unexplained temperature offset [ISSUE #9]
  — Behavior during calibration testing includes offset variation with time or temperature on D0 only
  — Cooler was operated without temperature feedback control (open loop) during a portion of calibration. Stability appears sufficiently stable to consider this as a legitimate back-up plan if D0, D1, and focal plan temperature control fail.
  — Not a “Mission Concern” because back up plans proven

• Operational heaters for Lens Assembly and Cal Mirror underpowered [ISSUE #12]
  — Diode unit installed to allow dual powering of A-side and B-side heaters simultaneously from only the A-side quiet bus or the B-side quiet bus
  — Sufficient heater authority demonstrated during calibration testing
    ▪ Analysis show that at PFM cold orbit predicts, heaters have increased authority. This is sufficient for mission success
  — Not a “Mission Concern” because heater authority increased.
Issues from Instrument Level Environmental Testing

- CS02 Testing Deficiency [ISSUE #20]
  - EMC testing indicated processor reset during CS02
  - Threshold levels never established during Instrument Level Environmental Testing
  - Planning for retest at TRW before integrating onto the Observatory
  - TRW investigating Secondary Converter Unit (SCE) output behavior
  - If testing at TRW indicates unacceptable susceptibility, then additional filter box will be considered for integration onto the appropriate place in the larger Observatory (S/C + Instrument) System

- ISSUE #20 is not considered an issue preventing shipment of the instrument to the Observatory

- Likewise, this is not considered an issue requiring extending the instrument’s time in-residence at Oxford.
New Issues Since PSR (I)

- Instrument Telemetry Loss Events (Anomaly Report 017 – ISSUE #17)
  - 2 instances of telemetry loss coincident with current spike
  - Occurrence only in calibration configuration
  - Troubleshooting via Fishbone thought process
    - Brainstormed all sources of telemetry loss and current spikes
    - Brainstormed action items to mitigate and find root cause
    - Action Items Implemented including
      + Changing power supplies (QB)
      + Initiating a procedure to capture IPU memory if event occurs again
  - Since implementing actions, no recurrence of event.
  - 44 days of continuous operation since last event.
  - TMON will be established to gather data during I&T if event occurs on Observatory.
  - AR017 is not considered an issue preventing shipment of the instrument to the Observatory
  - Likewise, this is not considered an issue requiring extending the instrument’s time in-residence at Oxford.
Issue Uncovered Post-PSR (II)
Occurred in I&T Cal

- In Flight Calibrator (IFC) Temperature Telemetry Jumps (Anomaly Report 002 – ISSUE #13)
  - A-side precision temp telemetry jumps in ambient pressure tests (3 temp channels)
  - Occurrence in I&T and calibration configurations outside of chamber only
  - No occurrence on B-side
  - Theory for root cause involves a glitch occurring in the successive approximation Analog-to-Digital conversion. This glitch sensitivity appears to be a design ‘feature.’
    - Oxford has modeled the glitch theory using Pspice and confirms it is feasible.

- Immediate investigation activities
  - Breadboard being assembled to assess theory and that issue is a design feature.
  - GSFC radiation group asked to examine parts for sensitivity to radiation that might indicate a degrading problem with time.
  - Testing instrument at minimum voltage region during Orbit sims

- AR002 is not consider an issue preventing shipment of the instrument to the Observatory

- Likewise, this is not considered an issue requiring extending the instrument’s time in-residence at Oxford.
ICF Telemetry Jump (III)

- ICF Temp Telemetry Jumps – What do we do? (Cont’d)

- Test Breadboard
- Investigate Low Voltage Influence
- Investigate Radiation Aging Influence

Decisions:

- If Confirms Theory:*
  - N: Watch List & Trend During I&T
  - Y: Expect to Degrade?

- If Expect to Degrade:
  - N: Behavior Degrading?*
    - N: Watch List & Trend During Ops
    - Y: Pull HIRLDS from Obs. Retrofit
  - Y: Pull HIRLDS from Obs. Retrofit

- If Y: Design BEU Heaters

- If N: Update Pspice Model & Design Fixes

- If Need Ground Cal:*
  - N: Retro-fit
  - Y: Re-Calibrate HIRDLS

- If N: Replace HIRLDS on Observatory

---

*Note: Y and N indicate yes and no responses respectively.
Issue Encountered During Cal (VI)

- “Jitter” in Calibration (Anomaly Report 009 – ISSUE #14)
  - Mechanical Disturbances are larger in magnitude than experienced during I&T testing
  - Disturbance source isolated to mechanical vibration of cooler
  - Jitter issue doesn’t impact calibration
    - Cooler operated at lower cooler frequency
    - Jitter can be filtered out-of-data
    - Modifications to test set-up reduce jitter (indium insertion)
- Not expected to be an on-Observatory Issue. Aura structures engineers estimated vibration levels and estimated that Observatory Jitter still remains under requirements.
- “Jitter” in Calibration is not consider an issue preventing shipment of the instrument to the Observatory
- Likewise, this is not considered an issue requiring extending the instrument’s time in-residence at Oxford.
Anomaly Worst Case Effect On-Orbit And Operations Work Around Strategy (I)

• Telemetry Loss (ISSUE #17)
  – Instrument stops sending telemetry
  – Workaround: TMON/SCS shuts down instrument, Ground contact brings instrument back on
  – IMPACT: Less science gathered during mission

• Jitter (ISSUE #14)
  – If instrument or spacecraft mechanical disturbances effect pointing
  – Workaround: Disturbances filtered-out via post processing & cooler frequ. changed
  – IMPACT: Larger FOV and LOS knowledge error bars in analysis. Depending on frequency and amplitude, could render instrument severely degraded or useless. IMPORTANT TO NOTE: No current data implies this!

• IFC Telemetry Jumps (ISSUE #13)
  – Assuming anomaly occurs in vacuum, degrades with time and occurs on both sides of the instrument, then we lose ability to calibrate to a known black body target.
  – IMPACT: In-flight calibration to known precision black-body temperature missing. HIRDLS accuracy severely degraded. Science team considering workarounds.
Anomaly Worst Case Effect On-Orbit And Operations Clearing Strategy (II)

• CS02 Resets (ISSUE #20)
  – If HIRDLS is not compatible with S/C SCE, then instrument stops sending telemetry
  – Workaround: Instrument safe’s itself, then ground contact brings instrument back on
  – IMPACT: Less science gathered during mission

• Cryodiode Temperature Sensor (ISSUE #9)
  – If D0, D1 and focal plan temperature control fails, then detector temperatures will fluctuate
  – Workaround: Ground control will initiate CSS constant stroke method of pump control
  – IMPACT: Post processing must account for varying detector temperatures with orbit
Issues Summary

• Issues to date are understood from an impact to science perspective

• Work arounds are conceived if issues develop during on-orbit operations

• No issue prevents breaking configuration in Oxford and shipping the Instrument to the Observatory
Calibration Objectives
Christopher Palmer
PFM Calibration

• Objective: Characterize instrument parameters used explicitly or implicitly in the data retrieval process,
  
  — In-Flight Calibrator Output
  
  — Spectral Response Function
  
  — Field of View Function

• Approach: Operate PFM instrument in simulated orbit environment and gather data from multiple calibrated targets
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Contact Between Forward Models

The point of contact between Forward Models and Instrument Data is the HIRDLS radiance in channel $i$, $\bar{L}_i$:

$$\bar{L}_i(t) = \int g(t-\tau) \int F_{FOV} (n-n_0(\tau)) \int F_{spec} (\bar{v}) L(\bar{v}, n) d\bar{v} d^2n d\tau$$

Scan Mirror motion During FIR time

Instantaneous Field of View Pointing

Spectral Bandpass

Writing $L = GS (1 + kS) + O$

$\bar{L}_i$ is derived from telemetry and calibration data:

$$\bar{L}_i = \bar{L}_{IFC} \left( \frac{S^* - S_{*0}^*}{S_{*IFC}^* - S_{*0}^*} \right)$$

$S^* = S(1 + kS)$

$$\bar{L}_{IFC} = \bar{B}(T_{IFC}) + \varepsilon (\bar{B}(T_6) - \bar{B}(T_{IFC}))$$
Contact Between Forward Models

In These Equations:

- $L(\nu, n)$ is the on-orbit spectral radiance field
- $F_{\text{spec}}(\nu)$ is the spectral function in channel $i$
- $F_{\text{FOV}}$ is the instantaneous FOV function in channel $i$
- $g(t - \tau)$ represents smearing of the FOV by scan mirror motion
- $S$ represents telemetered counts in channel $i$ minus digital zero offset (known)
- $O$ represents the radiance offset
- The subscripts $IFC$ and 0 denote IFC and space views
- $k$ is the non-linear correction in channel $i$
- $\beta$ denotes the Planck function evaluated with the channel $i$ spectral function
- $T_{\text{IFC}}$ is IFC temperature
- $\varepsilon$ and $T_6$ are the emissivity (in channel $i$) and temperature of the cal. Mirror (M6)

$g(t - \tau)$ is the determined by known FIR filter coefficients.

The pointing calibration and $T_{\text{IFC}}$ calibration are known.
The main calibration targets are thus $F_{\text{FOV}}, F_{\text{spec}}, k$ and $\varepsilon$ in all 21 channels,
And verification of this calibration algorithm.
## Calibration Requirements Cross-Reference Matrix

**Instr Parameter** | **Calib. #** | **Calibration Required** | **Output Required** | **Where Done**
---|---|---|---|---
**RADIOMETRIC CALIBRATION**

<table>
<thead>
<tr>
<th>Cal Reqmt #</th>
<th>IRD Para. #</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5.1</td>
<td>Non-linearity k for each channel</td>
<td>4.5</td>
<td>A precise characterization of the end-to-end non-linearity of each channel independent of spectral knowledge, at different detector temps.</td>
</tr>
<tr>
<td>2</td>
<td>2.5.1</td>
<td>IFC BB and Cal Mirror temps</td>
<td>8.1</td>
<td>Calibration algorithms for optics temp sensors.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8.2</td>
<td>Calibration algorithms and weighting coefficients for IFC BB temp sensors.</td>
</tr>
<tr>
<td>3</td>
<td>2.5.1</td>
<td>Cal Mirror (M6) emmissivity for each channel</td>
<td>4.1/4.2</td>
<td>Background scan w/ EBB at nominal IFC temp, while varying the temp of M6 and the IFC BB in turn to extract the dependence of L_\text{BB} on mirror temp.</td>
</tr>
<tr>
<td>4</td>
<td>2.5.1</td>
<td>Scan stray</td>
<td>4.3</td>
<td>Background scan w/ EBB cold, while EBB is moved over the elevation scan range.</td>
</tr>
</tbody>
</table>
## Calibration Requirements

<table>
<thead>
<tr>
<th>Cal Reqmt #</th>
<th>IRD Para. #</th>
<th>Instr Parameter</th>
<th>Calib. #</th>
<th>Calibration Required</th>
<th>Output Required</th>
<th>Where Done</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1.3</td>
<td>Position, velocity and attitude RSE in ECIRF</td>
<td>N/A</td>
<td>Orbital data is only relevant in flight.</td>
<td>N/A</td>
<td>On-orbit</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Gyro sensitivities to temperature and magnetic field</td>
<td>10.1</td>
<td>Calibration algorithms for gyro magnetometers.</td>
<td>Gyro magnetometer calibrations, gyro sensitivity to B field, T</td>
<td>At SS level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.3</td>
<td>Gyro sensitivities to temp.</td>
<td>Gyro magnetometer calibrations, gyro sensitivity to B field, T</td>
<td>At SS level</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Gyro axes $V_n$ wrt TRCF</td>
<td>9.1</td>
<td>Directions of the four gyro input axes $V_n$ as vectors relative to the TRCF.</td>
<td>Input axis vectors $V_n$</td>
<td>At SS level</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Alignment Data $R_{TI}$ and $R_{IS}$</td>
<td>9.2</td>
<td>Direction cosine rotation matrix $R_{TI}$ between TRCF and HIRDLS IRCF.</td>
<td>Rotation matrices $R_{TI}$, $R_{IS}$</td>
<td>At SS level</td>
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<tr>
<td></td>
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<td></td>
<td>9.3</td>
<td>Direction cosine rotation matrix $R_{IS}$ between HIRDLS IRCF and SRCF.</td>
<td>Rotation matrices $R_{TI}$, $R_{IS}$</td>
<td>At SS level</td>
</tr>
</tbody>
</table>
## Calibration Requirements

<table>
<thead>
<tr>
<th>Cal Reqmt #</th>
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<th>Output Required</th>
<th>Where Done</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LOCATION OF RADIANCES</td>
<td></td>
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<tr>
<td>9</td>
<td>2.8.3.1</td>
<td>Alignment Data for Scan Mirror</td>
<td>9.4</td>
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<td>Rotation matrices and vectors</td>
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<td>9.5</td>
<td>Directions of the POA $V_b$ and field rotation datum $V_r$ rays incident upon the scan mirror as vectors in the TRCF.</td>
<td>Rotation matrices and vectors</td>
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<td>Scan mirror position as fcn of telemetry</td>
<td>7.1</td>
<td>Calibration algorithms for elevation angle encoder.</td>
<td>Calibration algorithm for mirror az., mirror el., and wobble sensors</td>
<td>At SS level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.2</td>
<td>Calibration algorithms for azimuth angle encoder.</td>
<td>Calibration algorithm for mirror az., mirror el., and wobble sensors</td>
<td>At SS level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.3</td>
<td>Calibration algorithms for wobble sensors.</td>
<td>Calibration algorithm for mirror az., mirror el., and wobble sensors</td>
<td>At SS level</td>
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<td>11</td>
<td>2.6.3.2</td>
<td>CHILOS offsets wrt ILOS</td>
<td>6.1</td>
<td>2D field response profile for each channel, at various instr and detector temps.</td>
<td>CHILOS az and el offsets wrt ILOS</td>
<td>At instr level</td>
</tr>
</tbody>
</table>
## Calibration Requirements Cross-Reference Matrix

<table>
<thead>
<tr>
<th>Cal Reqmt #</th>
<th>IRD Para. #</th>
<th>Instr Parameter</th>
<th>Calib. #</th>
<th>Calibration Required</th>
<th>Output Required</th>
<th>Where Done</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2.6.3.1 &amp; 2.6.2.1</td>
<td>IFOV wrt ILOS for each channel</td>
<td>6.1</td>
<td>2D field response profile for each channel, at various instr and detector temps.</td>
<td>FOV function for each channel, OOF responses</td>
<td>At instr level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.2</td>
<td>2D field response profile for each channel, at reduced spatial resolution and increased sensitivity to search for any small OOF responses.</td>
<td>FOV function for each channel, OOF responses</td>
<td>At instr level</td>
</tr>
<tr>
<td>13</td>
<td>2.4.2 &amp; 2.4.4</td>
<td>Spectral bandpass for each channel</td>
<td>5.2</td>
<td>Relative spectral response profile for each channel passband down to the 0.2% level, under various conditions of optical bench and detector temp.</td>
<td>Spectral fcn for each channel, out-of-band responses</td>
<td>At instr level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.3</td>
<td>Out-of-band response down to 0.01% level, under various conditions of optical bench and detector temp.</td>
<td>Spectral fcn for each channel, out-of-band responses</td>
<td>At instr level</td>
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<td>2.5.3</td>
<td>Noise for each channel</td>
<td>4.4</td>
<td>Background scan while EBB temp ramped over whole range in order to measure NEN at all input radiance levels.</td>
<td>Baseline set of NEN for each channel</td>
<td>At instr level</td>
</tr>
</tbody>
</table>
Calibration Test Configuration
Overview
Chris Hepplewhite
Overview of PFM Calibration

**Implementation:**

- Fully integrated calibration equipment:
  - All calibration stimuli are configured together with the HIRDLS Instrument in the vacuum chamber and can be operated together
  - All calibration stimuli are fully remotely controllable
  - Test Procedures are built from standard sub-procedures -> provides for flexibility and for application to multi-channels with change of parameters

- Sequence of tasks arranged in order of most importance or need
  - Calibration is ~ 3 month effort (Aug. 20 to Dec 02 as of Nov 13th!)
  - Effort is 24/7 with 3 shifts per day
  - Received Instrument, conducted BAT and installed Instrument into the chamber
  - Radiometric, spectral and FOV measurements made at nominal conditions
  - Off-nominal measurements made as time permits

- Resources are coordinated at Oxford with UCB/NCAR and Lockheed Martin and GSFC
HIRDLS Delta Pre-Ship Review

HIRDLS Calibration Facility
HIRDLS Delta Pre-Ship Review

View of instrument and calibration equipment inside the vacuum chamber mounted on the seismic mass.
Clean room and vacuum chamber

Chamber optical bench

Seismic isolator

Monochromator turret

HIRDLS Delta Pre-Ship Review
Plan of the instrument and external black body targets inside the vacuum chamber. The instrument is surrounded by cryopanels (not shown) mounted on the chamber. The Collimator-Monochromator test equipment is between the two external targets.
External calibration black body targets:

Two identical targets.

1.0 m deep x 0.26 m entrance aperture diameter.

Electrically jackable front and rear.

4 separately controlled temperature zones plus LN2 cooled outer jacket. 1.2 Kw of heating.

Temperature range 100 - 323 K.

Precision thermometry to few 10s of mK absolute.
Collimator/monochromator calibration equipment

- direction of collimated beam
- envelope of HIRDLS input beams reflected by paraboloid (+/- 0.95 deg)
- black mirror surround
- offset paraboloid mirror
- HIRDLS scan mirror position
- plane switching mirror shown in both positions
- plane switching mirror
- monochromator
- reference detector
- broad band source
View of CMS inside Chamber
Installing PFM into Chamber
Pre-Launch Radiometric Calibration Requirements
Christopher Palmer
**IRD Requirements**
The IRD requirement for radiometric calibration is IRD #2.5.1

The systematic error in the knowledge of the radiance must be at most the greater of:

1. 0.5% of the radiance for spectral channels 2 to 5 and 1% for the other channels
2. 100% of the specified radiometric noise

The calibration equipment consists of two blackbodies which illuminate the full HIRDLS aperture. They are radiometrically identical, but in normal use one is operated at a fixed low temperature, simulating the Space View, while the other operates at a variable temperature, simulating the Atmospheric View.

The test radiance is the difference between the radiance in these two views, and it is probably somewhat more accurate than the in-flight calibration.
**Pre-Launch Radiometric Calibration**

### Radiometric Measurements

<table>
<thead>
<tr>
<th>Cal #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>External BB/IFC cross-calibration</td>
</tr>
<tr>
<td>4.2</td>
<td>Direct measurement of Cal mirror emissivity</td>
</tr>
<tr>
<td>4.3</td>
<td>Measurement of elevation scan stray (best effort)</td>
</tr>
<tr>
<td>4.4</td>
<td>Measurement of Radiometric noise</td>
</tr>
<tr>
<td>4.5</td>
<td>End-to-end radiometric calibration and determination of non-linearity</td>
</tr>
<tr>
<td>4.6</td>
<td>Orbital simulation</td>
</tr>
</tbody>
</table>

**Notes:**

4.1 This measurement will cross-compare the IFC and external thermometry at the point where the targets have the same temperature.

4.2 This calibration measures the radiometric error introduced by the temp diff TBB – TM6.

4.3 This can only be done with useful accuracy in orbit.
Pre-Launch Radiometric Calibration Measurements and Results
J. Barnett/T. Eden
Radiometric Calibration

Measurements were of three main types:

1) Staircases of one external target, mainly from approx 100 K to approx 315 K in steps of 10-15 K at 100 K dropping to 5-7 K at 315 K. The dwell at each step was 30-90 minutes as necessary to achieve temporal and spatial target. Typically 2-3 days duration, possibly interrupted.

2) Linear ramps of one external target; few degrees per hour

3) Extended dwells at one temperature, sometimes with both external targets and the IFC and HIRDLS mirrors at common temperature and external target temperatures varied by a few tens of mK above and below to obtain coincidences.
Radiometric Calibration

Measurements are made in three ways:

1) Raster scanning across each of the two external targets and the IFC in turn. The raster was large enough to see the edges of the target to enable the centre location to be determined and guarantee clear views into the target for all channels and measurements of spatial variation.

2) Viewing the two external targets and the IFC in a continuous cycle for 4 sec each (12 seconds total cycle time). The dwell time was changed on a few occasions, e.g. 160 secs for some noise characterisation runs. The view directions were determined from occasional raster scans (and are not critical).

3) Stares into the external targets or IFC for minutes of hours, with possible short duration views of the other targets. These were used particularly for noise characterisation.
Primary Radiometric Calibration

Staircases of the full target temperature range were performed for

1) 62 K detector temperature; days 266-268;
2) 72 K detector temperature; days 281-283;
3) 62 K detector temperature; days 285-288.

These gave data on detector gain and its linearity, noise, offset stability, IFC/external target temperature cross calibration.

Smooth ramps were performed for:

1) 62 K detector temperature; days 252/253; 100K - 310 K;
2) 62 K detector temperature; day 279; 265K - 315 K;

The first gave a quick look at results that could be expected from staircases plus data on signal processing problems (preferred states, etc). The second was a much slower ramp that gave direct measurements of target radiance as a function of temperature for use in correcting IFC radiance deviations from nominal in orbit (and also gave data on preferred states, etc).
### Additional Radiometric Calibration Tests

**IFC Thermometry Calibration**

One or both external targets at the same temperature as IFC and if possible IFC calibration mirror and HIRDLS scan mirror. Target temperature(s) adjusted until obtained same radiances from them as IFC, and varied so that target radiance went above and below IFC radiance. I.e. HIRDLS used as transfer radiometer. This repeated at different temperatures (possible range approx 275-320K). Accurate to a few mK. Done on both A and B-sides since IFC uses different sensors. Most comprehensive results with both targets and IFC and mirrors at same temperature, but then no gain information at all (but do not need it since using radiance coincidences)

Days 268, 284, 313-315;

**HIRDLS Calibration and Scan Mirror Emissivities**

Calibration mirror emissivity determined by viewing IFC and varying calibration mirror temperature; also view warm and cold external targets to measure any gain and offset changes (continually cycle around views of IFC and external targets).

Scan mirror emissivity measured by viewing a cold target and varying scan mirror temperature (rely on gain stability and stability of internal mirrors)

Days 268, 269, 271, 272.
Additional Radiometric Calibration Tests

Cold target reflectivity

Both external targets at same temperature (to within few mK) at approx 90 K. Radiance differences give measure of repeatability and likely limit on reflectivity and other differences.

Days 281, 317

Radiometric Offset variation with Elevation Angle

External target viewed as jack up and down. Other target stationary and used as a reference. Performed with both external targets at same temperature (120 K used).

Day 317

Noise Characterisation

Short period noise measured under numerous conditions using 4-sec dwells into each target (including wide range of detector temperatures during cool-downs). Longer period variations measured during extended dwells (150 sec dwells at each telemetry rate in 296-321 K staircase on day 288/289), and cold target stare (5 hours on day 285).
Radiometric calibration ramp, external target 2, 23/24/25 September 2002
External Target 2 Temperature During Extended Dwell

Time (units of 2 minutes)
A-side/B-side operation

The IFC (In-Flight Calibrator, i.e. black body target) has redundant electronics and temperature sensors which are hard-wired to the redundant IPUs such that side-A IPU operates with side-A IFC and side-B IPU operates with side-B IFC. Each side has 3 high precision sensors (6 in all).

Hence side-A instrument operation uses different sensors from side-B.

These sensors are the fundamental source of radiometric gain calibration, so need to be related to international standards separately for the two sides. Direct cross-calibration between A and B side sensors is not possible at instrument level (it was done at subsystem level).

For calibration, HIRDLS operation was on:

1) Side-A for days 252 to 255.

2) Side-B for days 272 to 305.

3) Side-A for days 308 to present
• Radiometric data were taken at 30 different external blackbody temperatures (111 K – 321 K), in a staircase pattern from low to high.

• The cold blackbody was held fixed at ~ 90.5 K and was used as the cold “space-view.”

• The focal-plane array was held at its nominal temperature.

• Raster scans in azimuth (ϕ) and elevation (θ) imaged the faces of each external target (and IFC) to the focal-plane array.
Scan Mirror Raster Pattern Sequence

CBB  HBB  IFC

Elevation (deg)

Azimuth (deg)

6.690\times10^5  6.692\times10^5  6.694\times10^5  6.696\times10^5  6.698\times10^5

IEGSE Time (sec)
Images of Hot Blackbody as Seen by Channels 1-9
Radiometric Analysis Procedure

• Time cuts were imposed to focus on a raster pattern for a particular target (i.e., cold BB, hot BB, and IFC).

• Data samples were taken from angular cuts in $\theta$ and $\phi$ at the center of the external targets:

$$\theta_1 \leq \theta \leq \theta_2$$ where $\Delta \theta = 0.2^\circ$

$$\phi_1 \leq \phi \leq \phi_2$$ where $\Delta \phi = 0.2^\circ$

• These cuts for a particular channel were held fixed at all temperatures
Events passing these software “cuts” were used to calculate the mean and sample standard deviation (noise):

\[
x = \frac{1}{N} \sum x_i
\]

\[
s \equiv \left[ \frac{1}{N-1} \sum (x_i - \bar{x})^2 \right]^{1/2}
\]

For each channel, the mean signal output at each temperature was used to perform a radiometric linearity analysis where the detector signal \( S \) is given by: \( S = GL (1+kL) \).
Radiometric Analysis Procedure (con’t)

• Knowledge of the input flux of radiation to produce the output signal is needed for each temperature:

\[ \Phi_m = \int_{\lambda_1}^{\lambda_2} R(\lambda) B(\lambda, T) \, d\lambda \]

• Where \( R(\lambda) \) is the Reading response.
• The sample standard deviation can be used to calculate the noise-equivalent radiance (NER)
Radiometric Linearity Analysis for Channels 1-4

- Channel 1 Counts
- Channel 2 Counts
- Channel 3 Counts
- Channel 4 Counts

Linear (Solid), Quad (Dashed), $k=6.29 \times 10^{-3}$

Linear (Solid), Quad (Dashed), $k=-2.08 \times 10^{-2}$

Linear (Solid), Quad (Dashed), $k=-1.47 \times 10^{-2}$

Linear (Solid), Quad (Dashed), $k=-1.25 \times 10^{-2}$
Radiometric Linearity Analysis for Channels 9-12

Linear (Solid), Quad (Dashed), $k = -5.75 \times 10^{-3}$

Linear (Solid), Quad (Dashed), $k = -1.27 \times 10^{-2}$

Linear (Solid), Quad (Dashed), $k = -1.26 \times 10^{-2}$

Linear (Solid), Quad (Dashed), $k = -1.16 \times 10^{-2}$
Radiometric Linearity Analysis for Channels 18-21
Fitting Residuals for Channels 1-4
Fitting Residuals for Channels 9 - 12
Fitting Residuals for Channels 18 - 21
Noise-Equivalent Radiance in 7.5 Hz Bandwidth

Channel 5 (Triangle), Channel 11 (Diamond), Channel 20 (Square)

Channel 6 (Triangle), Channel 12 (Diamond), Channel 21 (Square)
Noise Equivalent Radiance Comparisons
Note: PFM Numbers Include Noise from Cold Target
Summary: Radiometric Calibration Results

- Radiance Determination Accuracy
  - Temperature Channels 2-4: Meet <0.5% requirement
  - All other channels: <1% requirement
- Noise-Equivalent Radiances
  - All channels well below IRD specifications
Calibration and Scan Mirror Emissivity Measurements

• Central to HIRDLS radiometric in-flight calibration is the requirement for the calibration mirror and IFC to be at the same temperature within about 1 K. Calibration mirror emissivity then not important (e.g. 1 K difference equivalent to 10 mK IFC change if mirror emissivity is 1 %). The IFC and Calibration Mirror are both thermostatted to achieve this.

• However, knowledge of Calibration Mirror emissivity will enable a correction to be made for temperature differences, and also place an upper bound on the error.

• The scan mirror is common to all views but the reflection angle varies. Hence emissivity mainly matters in that it may vary with angle. This variation is probably impossible to measure, but could be calculated if we know the emissivity.

• Calibration and scan mirror emissivities have been measured by viewing external or internal blackbody target while changing mirror temperature.

• Both mirrors have platinum resistance sensors (in addition to AD590s) which have been used to minimise the bias errors which have been experienced because of electrical interference.
Calibration and Scan Mirror
Emissivity Measurements (continued)

• In the case of the IFC mirror, the IFC is viewed while changing the mirror temperature, and the change in signal measured.

• In the case of the scan mirror, an external target at low temperature (100 K) is viewed while changing the mirror temperature.

• In both cases the scanner was made to view each external target plus the IFC in a sequence with a 4 second dwell time in each, the cycle being repeated indefinitely apart from occasional interruptions when raster scans were taken across each target.

• Final analysis is in terms of fractional signal change (relative to a 290 K black body) vs relative Planck Function change for the mirror at the central frequency of each channel. The slope of the curve gives the emissivity.

• Initial analysis shows slopes of order 0.011 (1.1 % emissivity) for the calibration mirror with no marked channel dependence, and 0.013 (1.3% emissivity) for the scan mirror with some systematic frequency dependence which may not be significant (the measurements are more difficult for the scan mirror because of the smaller temperature change and slower response).
Calibration View Mirror
Temperature Emissivity Measurements

Calibration view mirror temperature emissivity measurements - days 268/269
Mirror and IFC temperatures vs time

Time (hour of day from 00:00 on day 268)
Temperature (K)

- cal mirror temperature
- scan mirror temperature
- IFC temperature
IFC View Signal

IFC view signal minus starting value vs time 7 to 18 hours
(cal mirror temperature in C * 10)
Scan Mirror Emissivity

Scan mirror emissivity measurements days 271 and 272 - fractional signal vs fractional scan mirror radiance; gradient is emissivity

fractional signal change

fractional scan mirror radiance change

HIRDLS Delta PSR – Oxford University
21 November 2002
Scan Mirror Temperature Emissivity Measurements

Scan mirror temperature emissivity measurements - days 271 and 272

Temperature (K)

Time (hour of day)
Scan Mirror Emissivity Measurements

Scan mirror emissivity measurements days 271 and 272 - cold target counts as function of scan mirror temperature

HIRDLS Delta PSR – Oxford University
21 November 2002
Scan mirror emissivity measurements days 271 and 272 - fractional signal vs fractional scan mirror radiance; gradient is emissivity

fractional scan mirror radiance change

fractional signal change

ch1 ch2 ch3 ch4 ch5 ch6 ch7 ch8 ch9 ch10 ch11 ch12 ch13 ch14 ch15 ch16 ch17 ch18 ch19 ch20 ch21
## Radiometric Calibration Summary

<table>
<thead>
<tr>
<th>Item</th>
<th>IRD Requirement</th>
<th>Result</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiance knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systematic (Bias)</td>
<td>0.5% (Ch 2-5)</td>
<td>&lt;0.5%</td>
<td>Early results to date.</td>
</tr>
<tr>
<td></td>
<td>1% (Ch 1, 6-21)</td>
<td>&lt;1%</td>
<td>Early results to date.</td>
</tr>
<tr>
<td>Uncertainty (Noise)</td>
<td>&lt;1 NEN</td>
<td>~ 1 NEN</td>
<td>Early results to date.</td>
</tr>
</tbody>
</table>

- All measurements made for baseline conditions
- Quick look analysis completed
- Initial results indicate requirements are met
Pre-Launch Spectral Calibration Requirements
Christopher Palmer
Pre-Launch Spectral Calibration

IRD Requirements

• Spectral accuracy: 0.2 cm\(^{-1}\) allocated to test equipment
• Amplitude knowledge: 1\% of the peak between 1\% points, 100\% of the value between 1\% and 0.2\% points
  Possible post-launch change 0.5\%
  Pre-launch characterization 0.5\%
• Spectral resolution 1 cm\(^{-1}\), 3 samples per resolution element
• Out-of-band requirements – 0.5\% of integrated response
• The key choices are type of spectral selection (Monochromator) and imaging arrangement (slit to field). These and the bandwidth requirement specify the size of grating required (102 mm), and the focal length of the collimator to fill the PDB.
Spectral knowledge requirements

Calibration requirements shown for channel 13 bandpass defining filter.

Item 0b4c2 (PFM-1) measured at 297 K in f6.2 beam
Pre-Launch Spectral Calibration

Spectral Measurements

<table>
<thead>
<tr>
<th>Cal #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Polarization study on selected channels</td>
</tr>
<tr>
<td>5.2</td>
<td>Measurement of In-band Spectral Response</td>
</tr>
<tr>
<td>5.3</td>
<td>Measurement of Out-of-band Spectral response</td>
</tr>
</tbody>
</table>

Notes:
5.1 All measurements under 5.2 will be repeated at two polarizer settings to extract the unpolarized response.
5.3 These measurements are taken over the range 1.6 – 20 µm at maximum source temperature.
Pre-Launch Spectral Calibration Results
In-Band – Tom Eden
Out-of-Band – J. Barnett/C. Palmer
Reduction of Spectral Response Data

• During each step of measurements, grating is moved to next position, measurements made by HIRDLS or reference detector with shutter open and shutter closed;

• HIRDLS data through IEGSE, as function of time

• CMS data (grating position, shutter position, filter and polarizer positions, reference detector output) through LPC and TEQ data node as function of time

• Processing Steps:
  – Step 1: HIRDLS shutter open minus shutter closed, versus $\nu$ (each polarization)
  – Step 2: Step 1 data with channel – spectra removed (2 polarizations)
  – Step 3: HIRDLS Step 2 data/reference detector Step 2 data (2 polarizations)
  – Step 4: Combination of 2 polarization – Step 3 data (initial estimate) of final result
# Measurements Made and Analyzed to Step 1

<table>
<thead>
<tr>
<th>Channel Number</th>
<th>Filter In p=36</th>
<th>Filter In p=92</th>
<th>Filter Out p=36</th>
<th>Filter Out p=92</th>
<th>Gas Cell p=36</th>
<th>Gas Cell p=92</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A, N</td>
<td>A, N</td>
<td>A, N</td>
<td>A, N</td>
<td>FON</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A, N</td>
<td>A, N</td>
<td>A, N</td>
<td>A, N</td>
<td>FON</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A, N</td>
<td>A, N</td>
<td>A, N</td>
<td>A, N</td>
<td>FON</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>A, N</td>
<td>A, N</td>
<td>A, N</td>
<td>A, N</td>
<td>FON</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>FON</td>
</tr>
<tr>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>FON</td>
</tr>
</tbody>
</table>

**Entry Definitions:**
- **N** = Nominal detector temperature ~61 K
- **A** = Detector temperature = 71 K
- **FI** = Filter In
- **FO** = Filter out

**Polarization State:**
- **p = 36** (horizontal)
- **p=92** (vertical)

**Note:** The above table does not include other measurements done at other polarization settings, i.e., Day 296: where channel 5 was examined at other polarization settings to help resolve the feature at p=92.
There also were repeat measurements done for certain cases. These are also NOT shown.
<table>
<thead>
<tr>
<th>Channel Number</th>
<th>Filter In p=36</th>
<th>Filter In p=92</th>
<th>Filter Out p=36</th>
<th>Filter Out p=92</th>
<th>Gas Cell p=36</th>
<th>Gas Cell p=92</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
<td>FON</td>
</tr>
<tr>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
<td>FON</td>
</tr>
<tr>
<td>9</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
<td>FON</td>
</tr>
<tr>
<td>10</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>FON</td>
</tr>
<tr>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>N</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>N</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
<td>FIN</td>
</tr>
<tr>
<td>16</td>
<td>A, N</td>
<td>A, N</td>
<td>N</td>
<td></td>
<td></td>
<td>FIN</td>
</tr>
<tr>
<td>17</td>
<td>A, N</td>
<td></td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>N</td>
<td>N</td>
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<td></td>
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<td>FIN</td>
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<td>19</td>
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<td>21</td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td>FIN</td>
</tr>
</tbody>
</table>
Collimator Output Measured by Reference Detector and Analyzed to Step 1+

TEQ Calibration Detector Measurements Matrix

<table>
<thead>
<tr>
<th>Channel Bandpass</th>
<th>Filter In p=36</th>
<th>Filter In p=92</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2 – 5</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>6 – 7</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>8 – 9</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10 – 11</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>13 – 15</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>16</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>17</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>18 – 20</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>21</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Note: The above table does not include other measurements performed at other polarization settings, or measurements that included gas cells.
HIRDLS In-Band Spectral Data
Step 1 Processing for Channel 8

Channel 8, 2002–293, p=92, Filter In

Channel 8, 2002–293, p=36, Filter In

Channel 8, 2002–293, p=36, Filter Out

Channel 8, 2002–293, p=36, Filter Out, Gas Cell
In-Band Spectral Data
Step 2 ("Dechanneling") for Channel 8
In-Band Spectral Data
Monochrometer Output Measured by Reference Detector Steps 1 & 2, Channel 8 & 9 (Filter In)

$y(x) = 0.556x - 435.309$

$y(x) = 0.889x - 662.155$
In Band Spectral Data
Steps 3 and 4 for Channel 8
Dotted Line = RDU Prediction
In-Band Spectral Data
Step 1 Data for Channel 4 Showing Expected Dependence on Focal Plane Temperature
In-Band Spectral Data
Other Step 4 Analysis Results
(Nominal Focal Plane Temperature)
Summary on In-Band Spectral Calibration
(16 November)

• Measurements have been made for all baseline in-band conditions
• Most measurements have been analyzed to Step 1
• Cases needing remeasurement (HIRDLS and Reference Detector) were identified and are being rerun
• Several channels have been fully analyzed (to Step 4), showing initial methodology has been established
• Wavelength accuracy is 0.24 cm\(^{-1}\), (compared to requirement of 0.2 cm\(^{-1}\))
• Response accuracy is being analyzed, (compared to requirement of 1%)
  – Factors involved include:
    ▪ Removing of filter channel spectra
    ▪ Channeling due to polarizer
    ▪ Source drift
    ▪ Reference detector S/N
• Analysis methodology will be improved and refined
Data gathered as per SP-OXF-277D which specifies segments A to H that cover the spectrum in contiguous sections, except that segment C and D were combined using the same polariser setting (they already needed the same grating and order sorting filter). G and H were similarly combined. The data were gathered to indicate areas for further investigation with the intention that strong responses would be measured in greater detail. A band I has also been added using the 150 lines/mm grating which otherwise is unused. This overlaps with spectral regions covered elsewhere.

Segments A and B were both run with and without order sorting filter to enable data to be gathered beyond the end of the range or order sorting filters. Both sets are given here.

Segments E and F were rerun using a wider range to help check on anomalies, and both versions are given here. (Channels 1-7 of F were also run a third time with the wider range).

Segment G+H was also rerun with the same range.

Four plots are given for each segment (or band - the word band is used synonymously with segment) - channels 1-21, channels 1-7 alone, channels 8-14 alone, channels 15-21 alone.

All runs were made at maximum entrance slit width, which in most cases means that signals are saturated at band centre; hence out-of-band responses of a few counts are generally several orders of magnitude less that the response that peak. Exit width was in all cases determined by the HIRDLS field of view. A smooth 100 steps/sec grating scan was employed.
Results are differences of shutter out minus shutter in.

Data were obtained at RDSR6 (500 samples/sec) with the FIR filter disabled. The shutter transition lost a few samples, and data with in 5 samples of a transition were not used.

Data were analysed by synchronously demodulating the data using the shutter 3 mafs-in/1 maf-out or 2 mafs-in/2 mafs-out pattern as appropriate, with the pattern being determined from an in-band channel (using separate runs with channel 21 for bands A and B which do not include a channel in band).

Each data point is centred on one of the 2 or 3 mafs open sequences, with the closed data for up to 1.0 mafs either side being used to subtract the background.

No other smoothing was employed, i.e. each data point is independent except that adjacent points share one common closed sequence.

No spike rejection method was employed. Spikes are all plotted. All channels are plotted. The only substantial spikes appear to be in Band G&H day 294/295 channel.

Start time of each scan relies on SAIL timing so spectral registration could be of order 100 grating steps out and this will vary from scan-to-scan. This is probably unavoidable.

Some out-of-band responses visible are almost certainly caused by test equipment deficiencies, e.g. Bands G and H show response in high number channels at a third of their filter frequency. Signal levels are very high for those channels (probably >>100000 chopped counts) so some observable breaking through of the order sorting filter is not surprising.
### Summary by Channel of the Features in the Out-of-Band Scans

<table>
<thead>
<tr>
<th>Channel</th>
<th>Long Wave</th>
<th>Main Peak</th>
<th>Short Wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Leak to about 10(\mu)m? Spurious</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Sidelobe 570</td>
<td>Leak to about 10 (\mu)m? Spurious</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Leak to about 10 (\mu)m? Spurious</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Sidelobe both sides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Sidelobe both sides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Plateau short side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sidelobe 850</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Sidelobes 920, 1060</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>[2nd 510]</td>
<td>Sidelobes 950, 1080</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>[2nd 570]</td>
<td>Sidelobes 1080, 1200</td>
<td>Unknown feature At 1630</td>
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<tr>
<td>13</td>
<td>[2nd 590]</td>
<td>Sidelobe 1140</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>[2nd 625]</td>
<td>Sidelobe 1190</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>[2nd ?]</td>
<td>Sidelobes 1200, 1360</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>[2nd ?]</td>
<td>Sidelobe 1200</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>[2nd ?]</td>
<td>Sidelobe 1200</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>[2nd 710]</td>
<td>Sidelobe 1480</td>
<td>Unknown feature At 2300</td>
</tr>
<tr>
<td>19</td>
<td>[2nd 710]</td>
<td>Sidelobe 1530</td>
<td>Unknown feature At 2300</td>
</tr>
<tr>
<td>20</td>
<td>[3rd 500, 2nd 760]</td>
<td>Sidelobe 1530</td>
<td>Unknown feature At 2400-2900</td>
</tr>
<tr>
<td>21</td>
<td>[3rd 520, 2nd ?]</td>
<td>Sidelobes 1300, 1450</td>
<td>Unknown feature At 3200</td>
</tr>
</tbody>
</table>
Band A No Filter Out-of-Band Response

Bands C and D Out-of-Band Response
Extended Band F Out-of-Band Response

Band G and H Out-of-Band Response

## Spectral Calibration Summary

<table>
<thead>
<tr>
<th>Item</th>
<th>IRD Requirement</th>
<th>Result</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectral knowledge</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wavelength accuracy</td>
<td>+/- 0.6 cm(^{-1}) (1%)</td>
<td>&lt;0.5 cm(^{-1})</td>
<td>Further analysis is expected to yield improvement.</td>
</tr>
<tr>
<td></td>
<td>+/- 1 cm(^{-1}) (0.2%)</td>
<td>&lt;1 cm(^{-1})</td>
<td>Further analysis is expected to yield improvement.</td>
</tr>
<tr>
<td>Amplitude knowledge</td>
<td>0.5% (1%)</td>
<td>&lt;0.1%</td>
<td>Simple scaling.</td>
</tr>
<tr>
<td></td>
<td>50% (0.2%)</td>
<td>&lt;0.1%</td>
<td>Simple scaling.</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>1 cm(^{-1}) (1%)</td>
<td>&lt;0.25 cm(^{-1})</td>
<td>Defined by monochromator settings.</td>
</tr>
<tr>
<td></td>
<td>2 cm(^{-1}) (0.2%)</td>
<td>&lt;0.25 cm(^{-1})</td>
<td>Defined by monochromator settings.</td>
</tr>
<tr>
<td>Out-of-band knowledge</td>
<td>&lt;0.5% IR or &lt;1 NEN</td>
<td>TBD</td>
<td>Data currently being analysed.</td>
</tr>
</tbody>
</table>

- All measurements made for baseline conditions
- Quick look analysis completed (less OOB knowledge)
- Initial results indicate requirements are met
Pre-Launch Field of View Calibration Requirements
Christopher Palmer
Pre-Launch Field-of-View Calibration

IRD Requirements

• Angular accuracy: 2 arc sec
  (relative to Quad Datum – includes within-Channel and Channel-to-Channel offsets)
  – Possible post-launch change 1.0 arc sec
  – Systematic Error of ILOS 0.2 arc sec
  – Systematic Deflection of Test Equipment 0.8 arc sec
• Amplitude Knowledge: 1% between 1% points, 100% between 1% and 0.2% points
  • Possible post-launch change 0.5%
    – Pre-Launch Characterization 0.5%
• Angular resolution 7 arc sec, 3 samples per resolution element
  – This is the diffraction limit in the shortest-wavelength channel
  – All channels mapped simultaneously – propose to use 15 arc sec element, three samples per element, or 20 arc sec for Chs 1-5, 10 arc sec for Chs 6-21
• Out-of-field requirements = 0.4% of integrated response
• Propose a low-resolution, high sensitivity map, with resolution of one channel field
Pre-Launch Field-of-View Calibration

### FOV Measurements

<table>
<thead>
<tr>
<th>Cal #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Two-dimensional FOV Map</td>
</tr>
<tr>
<td>6.2</td>
<td>High sensitivity/Low spatial resolution FOV map</td>
</tr>
<tr>
<td>6.3</td>
<td>Study of Out-of-field responses (from 6.2)</td>
</tr>
<tr>
<td>6.4</td>
<td>End-to-end FOV test (structured source)</td>
</tr>
</tbody>
</table>

**Notes:**

6.1 The FOV map repeated at two different Optical Bench temperatures. Because the FOV rotates, a two-dimensional map is necessary. Strictly this measures dynamic FOV, but at a speed where the dynamic contribution is negligible.

6.3 This study is contingent on finding unexpected out-of-field features.

6.4 This involves scanning over a double slit source at various scan speeds to check dynamic FOV, possible phase shifts etc.
Pre-Launch Field of View Calibration Results
J. Moorhouse/C. Palmer
Requirements

• These are divided into:
  1. Actual requirements
  2. Knowledge requirements
• Calibration is concerned with satisfying the latter
• These are laid down in the ITS and IRD, although further requirements have been more recently and informally introduced (e.g. vertical spatial response change with HIRDLS lens 2 temperature).
• Where IRD requirements must be budgeted further, the SPRAT requirements (System Performance and Allocation Tables) are used. These detail the flow from IRD to ITS.
Knowledge Requirements

• Knowledge requirements to be met by Oxford:
  1. **Vertical spatial response, VSR (i.e. the horizontally integrated response of a channel to radiation).** IRD 2.6.3.1
   
   i. The error in the knowledge of the relative VSRs to be at most 1% between the 1% relative response points (RRPs). Half of this is allowed for post-calibration changes.
   
   ii. The error in the knowledge of the relative VSR to be at most 100% between the 1% and 0.2% RRPs.
   
   iii. The spatial resolution for these measurements to be at most 33 μrad (100 m at the limb). This is smaller than the theoretical limit (the diffraction-limited spot size), therefore changed to the theoretical limit.
   
   iv. The relative position at which the response is measured must be known with an accuracy of 10 μrad (i.e. 30 m at the limb).

  2. **Vertical spatial response knowledge for a channel pair.** IRD 2.6.3.2
   
   i. For each pair of channels, the relative altitude angle between the centroids of the VSRs to be known to within 10 μrad (30 m at the limb) for channels 2-5 and twice this for all others.
Knowledge Requirements (con’t)

3. Horizontal spatial response: as vertical but accuracy/resolution relaxed by a factor of 5.

4. Out of field (OOF): nothing formal. It is understood that the Lockheed results (TC-NCA-090) for total OOF response are definitive (the Oxford facility is not equipped to produce integrated OOF responses). Oxford is to characterize the responses as far as possible (these are then normalized using the Lockheed results). IRD 2.6.2.1 specifies the response knowledge.

- Initial analyses show that the knowledge requirements are met with margin, with the exception of OOF. The quality of the OOF response is being investigated.
Actual Requirements

- These are laid down in the IRD 2.6.1, 2.6.2 and the ITS 3.3.1-3.3.5.
  1. Vertical response: define $\Delta z$ as the distance from the mid-point between the half-maximum points.
    a. Integrated response between half-maximum points must be at least 80% of total
    b. For $\Delta z = 0.75$ km, integrated response between $-\Delta z$ and $+\Delta z$ at least $(100-0.4\lambda)\%$
  - For $\Delta z$ between 1 and 4 km, $(100-0.25\lambda/\Delta z^{1.15})\%$
  - FWHM of $333\pm33$ μrad
  - FWHM of $3.33 \pm 33$ μrad (horizontal response)
- Out-of-field: the total OOF response must be less than 1% of the total integrated response when viewing the atmosphere / IFC.
Results

• The plot on the right is from a nominal in-field run made at the lower hot source temperature/ small FOV slit. The axes are shaft angle in degrees; each plot shows relative response scaled between max. and min. responses for each channel.

• Note the long purple swaths on channels 8, 9 and 5.

• The next two slides show shaded surface plots for several channels.
Matrix of Results (1st. draft)

<table>
<thead>
<tr>
<th>Aperture</th>
<th>Source temperature</th>
<th>CRT</th>
<th>T lens 1 [K]</th>
<th>T lens 2 [K]</th>
<th>Scan table(s)</th>
<th>T fp [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Hot</td>
<td>Warm</td>
<td>301</td>
<td>301</td>
<td>1,4,5</td>
<td>61</td>
</tr>
<tr>
<td>Large</td>
<td>Very hot</td>
<td>Warm</td>
<td>301</td>
<td>301</td>
<td>7</td>
<td>61</td>
</tr>
<tr>
<td>Medium</td>
<td>Very hot</td>
<td>Warm</td>
<td>301</td>
<td>301</td>
<td>1,5,7</td>
<td>61</td>
</tr>
<tr>
<td>Small</td>
<td>Very hot</td>
<td>Warm</td>
<td>301</td>
<td>301</td>
<td>1,3,5,7</td>
<td>61</td>
</tr>
<tr>
<td>Small</td>
<td>Hot</td>
<td>Warm</td>
<td>301</td>
<td>296,291</td>
<td>1,5</td>
<td>61</td>
</tr>
<tr>
<td>Small</td>
<td>Hot</td>
<td>Warm</td>
<td>301</td>
<td>306</td>
<td>1</td>
<td>61</td>
</tr>
<tr>
<td>Small</td>
<td>Hot</td>
<td>Warm</td>
<td>301</td>
<td>311</td>
<td>1,5</td>
<td>61</td>
</tr>
<tr>
<td>Small</td>
<td>Hot</td>
<td>Warm</td>
<td>307</td>
<td>301</td>
<td>1,5</td>
<td>61</td>
</tr>
<tr>
<td>Small</td>
<td>Hot</td>
<td>Warm</td>
<td>Cold</td>
<td>301</td>
<td>1,5</td>
<td>61</td>
</tr>
</tbody>
</table>
## Matrix of Results (1st. Draft con’t)

<table>
<thead>
<tr>
<th>Aperture</th>
<th>Source temperature</th>
<th>CRT</th>
<th>T lens 1 [K]</th>
<th>T lens 2 [K]</th>
<th>Scan table(s)</th>
<th>T fp [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Hot</td>
<td>Cold</td>
<td>301</td>
<td>301</td>
<td>1, 5</td>
<td>61</td>
</tr>
<tr>
<td>Small</td>
<td>Hot</td>
<td>Warm</td>
<td>301</td>
<td>301</td>
<td>1</td>
<td>71</td>
</tr>
<tr>
<td>Small</td>
<td>Very hot</td>
<td>Warm</td>
<td>301</td>
<td>301</td>
<td>3</td>
<td>71</td>
</tr>
<tr>
<td>Medium</td>
<td>Very hot</td>
<td>Warm</td>
<td>301</td>
<td>301</td>
<td>5</td>
<td>71</td>
</tr>
</tbody>
</table>

### Notes:

1. Table 1 = chs 1 - 21
   - Table 3 = chs 1 – 12
   - Table 4 = co-alignments chs 1 - 21 (repeated visits to ch 2)
   - Table 5 = co-alignment chs 1 - 15
   - Table 7 = out-of-field
   - Table 8 = co-alignment chs 1 - 15

2. Collimator hot source: hot ~400 K, very hot ~900 K

3. All tables use RDSR=6 except out-of-field (RDSR=1)

4. Seismic block is floated, cooler frequency is 35 Hz

5. Apertures: small: rectangle 0.13x1.0 km, medium: rectangle 0.27x1.0 km, large: rectangle 1x4 km.
Results

HIRDLS Delta PSR – Oxford University
21 November 202
Results

The channel 1 data was taken using a higher source temperature; even so, the noise is evident (but acceptable)
Results

Contour plots: FS2 appears as a rectangular structure
Results

The ‘purple swath’ of channel 5 is apparent from the wings of the above. FS2 causes the diffraction wings to be cut off.
Results

Plots with lens 2 temperature nominal, nominal-5° and nominal-10°
Results

Integrated responses compared to the requirement.
Results

FWHM, nominal temperatures

Full width at half maximum [km]

Channel

FWHM, nominal temperatures

Full width at half maximum [km]

Channel
Results

- Out-of-field response for channel 19. A ~900 K source temperature and the large OOF slit were used. Channel 19 is saturated (in fact the incident flux is very many times that required to saturate the channel), but any number of counts over 6000 is shown by the same colour.

- The next slides show OOF response for channel 1, and the shutter open response for channel 10 (this is done to show that adjacent channels fall in the `cone’ region of the face-plate, designed to be especially black.)
Results
FOV Calibration Summary

<table>
<thead>
<tr>
<th>Item</th>
<th>IRD Requirement</th>
<th>Result</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical spatial response</td>
<td>0.5% (0.5%)</td>
<td>&lt; 0.5%</td>
<td>Early results to date.</td>
</tr>
<tr>
<td></td>
<td>100% (0.2%)</td>
<td>&lt;100%</td>
<td>Early results to date.</td>
</tr>
<tr>
<td>Co-alignment</td>
<td>10(\mu)rad (Ch 2-5)</td>
<td>~ 5(\mu)rad</td>
<td>Early results to date.</td>
</tr>
<tr>
<td></td>
<td>20(\mu)rad (Ch 1,6-21)</td>
<td>~ 5(\mu)rad</td>
<td>Early results to date.</td>
</tr>
<tr>
<td>Out-of-Field knowledge</td>
<td>&lt;0.4% IR or &lt;1 NEN</td>
<td>TBD</td>
<td>Data currently being analysed.</td>
</tr>
</tbody>
</table>

- All measurements made for baseline conditions
- Quick look analysis completed (less OOF knowledge)
- Initial results indicate requirements are met
On-orbit Calibration Plans
J. Gille
On-orbit Calibration

• On-orbit calibration needed to measure instrument characteristics that may have changed since pre-launch calibration, and/or may vary in orbit, and which can only be done on orbit.

• HIRDLS On-Orbit Calibration
  — Radiometric Gain
    ▪ Change of detector temperature
    ▪ Aging of detector and electronic components or radiation damage
  — Position Dependent Stray Radiation
    ▪ Increased number of scatters on scan mirror and primary mirror
  — Scan Mirror Emissivity
    ▪ Condensation on mirror
    ▪ Aging or pitting of surface
  — Gyro Parameters
On-Orbit Radiometric Gain Calibration

Measurement Looking at Atmosphere

\[ S = G'L(1 + kL) + O \]

Signal \quad Gain \quad Radiometric Offset

Calibration requires determination of \( G' \) and \( O \)
Makes use of 2 point calibration

\[ S_0 = O \] \quad View of space at TOP of each scan, 1/20 seconds for \( \geq 50 \) samples

\[ S_{IFC} = G' L_{IFC} (1 + kL_{IFC}) + O \] \quad View of IFC \sim 1/minute, for \( \geq 1 \) sec

then

\[ L = N (1 - kN) \]

where

\[ N = L_{IFC} (1 + kL_{IFC}) \left( \frac{S - S_0}{S_{IFC} - S_0} \right) \]
On-Orbit Determination of Stray Radiation

• Observed on all scans from \( \partial L / \partial Z \) in regions above measurable signal; will be trended.

• Observed frequently by vertical scans to top of field of regard (FOR).

• Assessed about every 6 (TBV) months by 5 degree tip-down of platform in <30 minutes, so earth and atmosphere completely out of field of regard, and only scattered radiation seen.
On-Orbit Calibration of IFC Mirror Emissivity

• Generally try to operate cal mirror so $T_{IFC} = T_{calmirror}$, then $\varepsilon_6$ does not enter.

• If $T_{IFC} \neq T_{calmirror}$, then $\varepsilon$ determined by looking at signal from IFC as $T_{calmirror}$ changed (as done in lab).
On-Orbit Calibration of Gyro Parameters

• Scale factors, bias, and bias drifts checked against S/C gyro.

• MLS pitch-ups and HIRDLS pitch-downs provide additional conditions from which to determine gyro parameters.
SHIPMENT & INTEGRATION WITH OBSERVATORY
Paul Roycraft
Transit out of Oxford Cleanroom

- Oxford Team move instrument out of chamber

- Lockheed conducts the Release Test (similar to Bench Acceptance Test)

- Oxford and Lockheed Team disassemble the IEGSE

- Lockheed bags instrument

- Oxford and Lockheed team negotiate bagged instrument out of the cleanroom into loading bay area

- Oxford and Lockheed packing team places the instrument into the transport container and packs IEGSE and all other items
Lorry from Oxford to Stansted

• Items staged in loading bay are loaded onto transport by Oxford Team with GSFC assistance

• Loading and transport provided by UK removers with environmentally controlled truck with lift gate

• Accompanied by Oxford and GSFC escorts to Stansted Airport
Flight from Stansted, UK to Memphis, TN (Carrier: FedEx)

- GSFC escort 1 accompanies Instrument to Memphis on FedEx aircraft

- Met at Memphis by GSFC escort 2

- Customs clearance is arranged in advance and will be finalized upon shipment arrival in Memphis
Lay-over in Memphis

- Instrument is transferred directly from aircraft into climate-controlled vehicle during layover in Memphis and is monitored by GSFC escorts and FedEx security personnel

- Nominal layover in Memphis is 15 hours. If lay-over extends to over 120 hours, GN2 purge initiated

- Instrument is loaded into next aircraft

- Goddard Escort 2 witnesses operation and escorts flight to LAX
Flight from Memphis to LAX (Carrier: FedEx)

- GSFC escort 2 accompanies shipment to LAX on FedEx aircraft
- Arrives LAX and met by GSFC escort 3
- Items are offloaded and trucked to TRW
Truck from LAX to TRW

- GSFC escort 3 accompanies shipment to TRW
- Met by TRW IPL personnel at One Space Park, building M2N
- Acceptance into TRW facility follows procedures defined in TRW Activity Plan 01, summarized in the next slides
Instrument receiving at TRW

- Unload truck with fork lift with $\geq 6.5'$ tines or using lift gate within M2/1580

- Roll all equipment that goes directly to the control room and offices through the hallways to their respective areas. (Shop carts & pallet jacks may be required.)

- Visual inspection of outside of containers. Shock, temperature & humidity indicators are located inside of shipping container. Instrument is backfilled within the shipping container.

- Clean shipping container and transport cart to a visible level of cleanliness.

- Move Instrument from M2/1580 through roll up doors and into M2/1568. (Equipment is on wheels.)

- The Shipping Container cover is removed by four people within M2/1568.

- Connect ground strap to shipping container.
Instrument receiving at TRW (con’t)

- The Shipping Container top sections are placed on bagging material and covered with bagging material within M2/1568 for storage until the instrument is installed on the S/C.

- The shipping container base is cleaned.

- The outer metalized bag is then removed and stored under the shipping container top sections.

- The instrument is rolled into the Class 10,000 tent.

- Remove bag in the Class 10,000 tent

- Attach facility ground strap and connect purge as soon as possible

- Conduct inventory against shipper, tag items, physical inspection / clean if req’d. See HIRDLS Equipment Management Table for all special equipment required

- Receiving inspection of flight instrument within the Class 10,000 tent area
Instrument receiving at TRW (con’t)

- Review and sign off the shipping documents and receiving procedure

- Move empty containers, lifting slings, etc. into warehouse or ship back to IP (see HIRDLS Equipment Management Table)
HIRDLS – Receipt at TRW through S/C Mech./Elec. Integration

- TRW Facility Electrical And Environmental Preparation
- Logistics Readiness Review For HIRDLS Delivery 26 November 2002
- Truck Carrying HIRDLS Instrument & EGSE Arrives at TRW
- Unload Truck Visual Inspect Containers Move to M2/1580
- Move to Clean Room & Prep. Instrument for CPT/BAT
- Perform Safe-to-Mate and connect EGSE to Instrument
- Conduct Test Readiness Review
- Perform CPT-2 (Includes Data Analysis/Review & OK to Break Configuration)
- Set Up for CS02 Measurements & Conduct Test Readiness Review
- Conduct CS02 Measurements (Includes Data Analysis & Review and OK to Break Configuration)
- Perform LPT (Includes Data Analysis/Review & Ok to Break Configuration)
- Epoxy / Cure HDU
- Install Flight MLI
- Conduct Test Readiness Review
- Perform Final CPT (Includes Data Analysis/Review & OK to Break Configuration)
- Re-Shoot Alignment Cube
- HIRDLS Integration TRR
- Instrument / Spacecraft Mechanical Integration
- Instrument / Spacecraft Electrical Integration CPT Dry Runs
- Complete Instrument / Spacecraft Mechanical & Electrical Integration

Transport
21 November 2002

HIRDLS Delta PSR – Oxford University
Past Review Open Request-For-Action Status

Glenn Jackson
Critical Design Review RFAs Closure Plan

• All CDR RFAs Closed by Review Team Except QTY = 3:

• #8: Operations-Post Launch
  – “Please clarify the organization and planning for immediate post launch activities (say 0 to +14 days). (1) will a HIRDLS team be co-located with the spacecraft operations team? (2) When is it planned to open aperture doors and function mechanisms? (3) When is it planned to turn on detectors? (4) What attitude requirements need to be passed to the spacecraft controllers?”
  – Closure by GSFC before Aura Flight Operations Review (10/03). Not considered an impediment to shipping to Observatory by GSFC IM.

• #39 SAIL/IEGSE Pre-/Post Launch
  – “Describe the plan for IGSE, SAIL workstation, and simulator support for HIRDLS at TRW during Integration and Testing and at the launch site. Where will the science team be during I&T, during pre-launch launch site preparations, during launch, and during post-launch operations and maintenance periods? Where did the requirement for extra operations centers come from?”
  – Closure by GSFC before Aura Flight Operations Review (10/03). Not considered an impediment to shipping to Observatory by GSFC IM.

• #40 SAIL and Ops Center
  – “Co-locate a SAIL compiler workstation and simulator for testing SAIL microloads in the EOS-CHEM Operations Center. Provide a communications plan describing how SAIL microloads, new STOL procedures, software patches, etc. will be transferred securely and without error to the EOS-CHEM Operations Center. Determine the protocols for transferring command requests from the instrument scientists to operations.”
  – Closure by GSFC before Aura Flight Operations Review (10/03). Not considered an impediment to shipping to Observatory by GSFC IM.
PER RFAs & Closure Plan

• All PER RFAs Closed by Review Team Except 2

• #12 VERTICAL POSITION ERROR BUDGET
  — “Provide end-to-end vertical position error budget showing allocation of errors for encoder accuracy, gyro accuracy, timing & ephemeris errors. Include assumptions for on-orbit calibration of GSS alignment, scale factor & bias.”

  — Closure by GSFC & Oxford. Gathering data for response, expect to close Jan. ’03. Not considered an impediment to shipping to Observatory by GSFC IM.

• #13 GYRO PERFORMANCE DATA
  — “Provide gyro acceptance performance data. GSS performance data was not presented. Gyro scale factors presented show difference of 50% between gyros – is this correct?”

  — Closure by GSFC & Oxford. Gathering data for response, expect to close Jan. ’03. Not considered an impediment to shipping to Observatory by GSFC IM.
Pre Ship Review RFAs & Closure Plan

• RFAs 1, 2, 5, 6, 10 are in review with the board

• RFAs 3, 4, 7, 8, 9 are in work:

• **#3 Lens Heater Authority**
  - “a) Recommend that the heaters used on the mirrors and lenses in the optical train be modified to meet industry guidelines. (Calibration Mirror, Germanium Lenses 1 & 2, SMA, and Blackbody.) Heaters should have a maximum of 75% duty cycle at acceptance minimum temperature.
  - b) Describe penalty testing performed to verify the fix.
  - c) Show that the fix does not result in loss of reliability.”

  — *Closure* by LM. Not considered an impediment to shipping to Observatory by GSFC IM.

• **#4 D0 Cryodiode Anomaly**
  - “1. Explain in detail how assumed damage to the cryo-diode wiring caused the offset and behavior seen in TV tests.
  - 2. Change cooler control software to remove the cryo-diode offset.
  - 3. Provide the manner of cooler control assessment assuming both cryo diodes have failed, if such a method exists.

  ”

  — *Closure* by LM. Not considered an impediment to shipping to Observatory by GSFC IM.
• #7 Transient Data Fast Capture for Requirement Verification
  — “Review and assess the adequacy of power bus transient and ripple measurements with respect to ability to capture fast transients.”

  — Closure by LM. Not considered an impediment to shipping to Observatory by GSFC IM.

• #8 28 Volt Oscillations
  — “Ensure that the Interpoint Converter 28 Volt oscillation under lightly loaded conditions does not cause overstress and will remain within predictable bounds.”

  — Closure by GSFC. Parts not overstressed, conditioned only expected in non-flight conditions. Evaluation by Orlowski underway regarding predictable bounds. Not considered an impediment to shipping to Observatory by GSFC IM.

• #9 Dropped Commands
  — “Regarding Mission Success Instrument Review Finding #5: Provide the PSR Review Team with the final recommendation from your follow-up of this issue. Ensure that a “dropped command” from the Aura Bus is not a hazard during a safing or load shedding sequence. Ensure that the Instrument will not be left in an undesirable configuration due to a “dropped command.” Determine whether duplicate, multiple commands (or command sequences) should be sent during safing or load shedding to ensure that one gets through.”

  — Closure by LM. Not considered an impediment to shipping to Observatory by GSFC IM.
• No open RFAs prevent shipment of Instrument from Oxford to Observatory.
HIRDLS Delta Pre-Ship Review

P.I.’s Assessment

John Gille
Radiometric Calibration

• Data Collection
  – Data collected for several sequences of O(30) staisteps in external blackbody (EBB) temperature, from 100 – 320 K for $T_{FP} \approx 62$ K and 72 K

• Data Analysis Status and Results (18 Nov)
  – Data for 12 channels analyzed for $T_{FP} \approx 62$ K
  – Non-linearity coefficient $k$ determined
  – Cross-calibration of IFC and EBB’s appears very good

• Assessment of measured data quality
  – Data quality appears very good

• Issues
  – No data for $T_{FP} = 72$ K analyzed to date; quality unverified (additional analysis needed) *Analysis performed since production of this slide show no concerns.*
  – Variation of $k(T)$ (assume smooth otherwise run radiometric tests at FP3)
Spectral Calibration (In Band)

• Data Collection
  – Measurement made for all channels for TFP \( \approx 62 \) K and 72 K
  – HIRDLS – 2 polarizations, filter in and out, gas cell
  – Ref. Detector – 2 polarizations, filter in and out, gas cell

• Data Analysis Status and Results (18 Nov)
  – 5 channels fully analyzed (Level 4)
  – All channels analyzed to Level 1 for TFP = 62 K

• Assessment of Measured Data Quality
  – Most complex measurements and data reduction
  – Data later than day 288 good, analyzable

• Issues
  – Some measured data not analyzed to Level 1, re-runs possibly necessary
    ▪ Lambert and Mankin working through Level 1 analysis to determine if re-runs required
      Since production of this slide, quick look analysis of Ch 1-4 show no concerns.
  – Ref. detector low S/N
  – Residual channel spectra (?) may make 1% accuracy a challenge
Spectral Calibration (Out-of-Band)

- **Data Collection**
  - Measurements made over entire range passed by optical materials (2.6 - 20\(\mu\)m) for all channels @ \(T_{fp}=62\) K

- **Data Analysis Status and Results (18 Nov)**
  - Data inspected. Few features seen

- **Assessment of Measured Data Quality**
  - Data quality appears very good.

- **Issues**
  - Nature of Features – Real or Artifacts? *Since production of this slide, quick look analysis of this indicate features are most likely artifacts.*
  - In-band signal saturate – difficult to quantify relative strength
    - Possible re-run at lower source temperatures
  - Polarization sensitivity of some features (?)
Field of View Calibration (In Field)

• Data Collection
  – Many raster scans over all channels @ $T_{FP} = 62, 72$ K
  – Raster scans to determine FOV spacing @ $T_{FP} = 62$ K
  – Measurements made with warm SVA target (non-linearity effects)
  – Early measurements subject to large jitter perturbations required re-runs

• Data Analysis Status and Results (18 Nov)
  – FOV data @ $T_{FP} = 62$ K analyzed for all channels and FOV spacing

• Assessment of Measured Data Quality
  – Data quality appears very good

• Issues
  – De-convolution of FOV shape (further analysis necessary)
  – Locating centroid, determining FOV positions to 10 or 20 $\mu$rad rel. to Ch. 2
  – Non linearity w. warm SVA target introduces significant errors
    ▪ Reruns with cold SVA target to reduce nonlinearity effects
Field of View Calibration (Out of Field)

• Data Collection
  – Rasters with large slit at sequence of detector positions for $T_{FP} \approx 62$ K
  – Many measurements with warm SVA target, leads to larger non-linearities
  – No scans for $T_{FP} = 72$ K
• Data Analysis Status and Results (18 Nov)
  – Inspection of data
  – Some quantitative analysis underway
• Assessment of Measured Data Quality
  – Data quality of existing data appears very good
  – Large dynamic range of in-field vs. out-of-field may require additional scans with lower temperature source. Additional runs with lower T source, to facilitate quantitative determination of relative feature strength.
• Issues
  – Are features real or artifacts? (Re-examination of the existing data)
  – How well can size of out-of-field features be quantified? (further analysis)
  – What is root cause of out-of-field response? (similar to first issue)
  – How stable are out-of-field responses? (Short term appears stable, but might move in longer term)
  – How well can corrections be made? (Data processing approaches need to be considered)
Update to Instrument Concerns Emerging at PSR

• FOV is found to be 1.2 km
  – 1.2 Km acceptable
  – Addition of HDU greatly increases likelihood that temperature of lens L2 can be maintained at 301 K as specified under all orbital temperature conditions Additional FOV measurements

• Capacity of inflight calibrator (IFC) relay mirror did not control within 1 K of IFC black body
  – HDU allows control within 1 K. Problem has now been fixed with HDU.

• Temperature of warm filters (+ Lens 1) <301 K at minimum operating temperatures. This results in spectral shift of filter
  – Additional calibration in progress (warm filters running at 291 K on Tues, 19-Nov)

• Out-of-Field Response
  – Planned additional measurements at Oxford has shown structure in out-of-field response
  – In coming week
    ▪ OOF scans with lower BB temp (broader range of response in ‘wings’)
  – Data analysis in progress. Tight requirement, difficult test
  – Initial indication requirement may be met, or effect is correctible
  – No evaluation of scientific impact at this time
P.I.’s Assessment

High Resolution Retrieval of Tropical Tropopause Water Vapor

Retrieved vs True

Altitude (km)

H2O (ppmv)

1.0 km
HIRDLS Delta Pre-Ship Review

Closure

Chris Hepplewhite
Closure Agenda

- PI’s assessment of calibration and issues to date
- PM’s assessment of tasks complete
- Summary of tasks remaining
Closure

- Finish data acquisition and release HIRDLS to TRW.

Questions:

- When will we have all the necessary pre-launch calibration data?
- How do we know when we have all necessary data?
• **Answers:**

• All the baseline measurements were pre-defined including:
  - Spatial Response ($T_{FP}$, $T_{LN1}$, $T_{LN2}$): in-field, out-of-field, co-alignment;
  - Spectral Response ($T_{FP}$, $T_{LN1}$): in-band, out-of-band
  - Radiometric Calibration (A/B-side, $T_{FP}$, $T_{IFC}$): non-linearity; cross calibration; mirror emissivity
  - Supporting Measurements: cross-talk; orbital thermal cycle; scan stray; monochromator cal detector
Closure

• **Answers (continued)**

2a) Do the data encompass the ranges required?
2b) Do they have sufficient fidelity (stability; SNR; etc.)?
   - Quick look – 75% complete
   - First stage – 25% complete, feedback provided

2c) Where are the uncertainties on the derived quantities (FWHM)?
   - Requires detailed analysis – 10% complete
   - Will take many man-months
   - Some initial results are coming in
## PRE-LAUNCH CALIBRATION SUMMARY

<table>
<thead>
<tr>
<th>Item</th>
<th>IRD Requirement</th>
<th>Result</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radiance knowledge</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systematic (Bias)</td>
<td>0.5% (Ch 2-5)</td>
<td>&lt;0.5%</td>
<td>Early results to date.</td>
</tr>
<tr>
<td></td>
<td>1% (Ch 1, 6-21)</td>
<td>&lt;1%</td>
<td>Early results to date.</td>
</tr>
<tr>
<td>Uncertainty (Noise)</td>
<td>&lt;1 NEN</td>
<td>~ 1 NEN</td>
<td>Early results to date.</td>
</tr>
<tr>
<td><strong>Spectral knowledge</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wavelength accuracy</td>
<td>+- 0.6cm(^{-1}) (1%)</td>
<td>&lt;0.5cm(^{-1})</td>
<td>Further analysis is expected to yield improvement.</td>
</tr>
<tr>
<td></td>
<td>+- 1cm(^{-1}) (0.2%)</td>
<td>&lt; 1 cm(^{-1})</td>
<td>Further analysis is expected to yield improvement.</td>
</tr>
<tr>
<td>Amplitude knowledge</td>
<td>0.5% (1%)</td>
<td>&lt;0.1%</td>
<td>Simple scaling.</td>
</tr>
<tr>
<td></td>
<td>50% (0.2%)</td>
<td>&lt;0.1%</td>
<td>Simple scaling.</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>1 cm(^{-1}) (1%)</td>
<td>&lt;0.1%</td>
<td>Defined by monochromator settings.</td>
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<tr>
<td></td>
<td>2 cm(^{-1}) (0.2%)</td>
<td>&lt;0.1%</td>
<td>Defined by monochromator settings.</td>
</tr>
<tr>
<td>Out-of-band knowledge</td>
<td>&lt;0.5% IR or &lt;1 NEN</td>
<td>&lt;0.25cm(^{-1})</td>
<td>Data currently being analysed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;0.25cm(^{-1})</td>
<td></td>
</tr>
<tr>
<td><strong>Spatial knowledge</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical spatial response</td>
<td>0.5% (0.5%)</td>
<td>&lt; 0.5%</td>
<td>Early results to date.</td>
</tr>
<tr>
<td>Co-alignment</td>
<td>100% (0.2%)</td>
<td>&lt;100%</td>
<td>Early results to date.</td>
</tr>
<tr>
<td></td>
<td>10(\mu)rad (Ch 2-5)</td>
<td>~ 5(\mu)rad</td>
<td>Early results to date.</td>
</tr>
<tr>
<td>Out-of-Field knowledge</td>
<td>20(\mu)rad (Ch 1,6-21)</td>
<td>~ 5(\mu)rad</td>
<td>Early results to date.</td>
</tr>
<tr>
<td></td>
<td>&lt;0.4% IR or &lt;1 NEN</td>
<td>TBD</td>
<td>Data currently being analysed.</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Or as partitioned to calibration.
# Calibration Requirements
## Cross-Reference Matrix

<table>
<thead>
<tr>
<th>Cal Reqmt #</th>
<th>IRD Para. #</th>
<th>Instr Parameter</th>
<th>Calib. #</th>
<th>Calibration Required</th>
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<th>Where Done</th>
<th>Data Acquired</th>
<th>Analysis Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5.1</td>
<td>Non-linearity k for each channel</td>
<td>4.5</td>
<td>A precise characterization of the end-to-end non-linearity of each channel independent of spectral knowledge, at different detector temps.</td>
<td>k for each channel, and dependences</td>
<td>At instr level</td>
<td>Done</td>
<td>Quick Look</td>
</tr>
<tr>
<td>2</td>
<td>2.5.1</td>
<td>IFC BB and Cal Mirror temps</td>
<td>8.1</td>
<td>Calibration algorithms for optics temp sensors.</td>
<td>Calibration algorithm for each sensor</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<tr>
<td></td>
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<td></td>
<td>8.2</td>
<td>Calibration algorithms and weighting coefficients for IFC BB temp sensors.</td>
<td>Calibration algorithm for each sensor</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<td>3</td>
<td>2.5.1</td>
<td>Cal Mirror (M6) emmissivity for each channel</td>
<td>4.1/4.2</td>
<td>Background scan w/ EBB at nominal IFC temp, while varying the temp of M6 and the IFC BB in turn to extract the dependence of L_{BB} on mirror temp.</td>
<td>Emmissivity of M6 for each channel</td>
<td>At instr level</td>
<td>Done</td>
<td>Detailed</td>
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<tr>
<td>4</td>
<td>2.5.1</td>
<td>Scan stray</td>
<td>4.3</td>
<td>Background scan w/ EBB cold, while EBB is moved over the elevation scan range.</td>
<td>Scan stray model</td>
<td>On-orbit</td>
<td>N/A</td>
<td>N/A</td>
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</table>
## Calibration Requirements

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<tbody>
<tr>
<td>5</td>
<td>2.1.3</td>
<td>Position, velocity and attitude RSE in ECIRF</td>
<td>N/A</td>
<td>Orbital data is only relevant in flight.</td>
<td>N/A</td>
<td>On-orbit</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>6</td>
<td></td>
<td>Gyro sensitivities to temperature and magnetic field</td>
<td>10.1</td>
<td>Calibration algorithms for gyro magnetometers.</td>
<td>Gyro magnetometer calibrations, gyro sensitivity to B field, T</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<td>10.3</td>
<td>Gyro sensitivities to temp.</td>
<td>Gyro magnetometer calibrations, gyro sensitivity to B field, T</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<td>7</td>
<td></td>
<td>Gyro axes V_n wrt TRCF</td>
<td>9.1</td>
<td>Directions of the four gyro input axes V_n as vectors relative to the TRCF.</td>
<td>Input axis vectors V_n</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<tr>
<td>8</td>
<td></td>
<td>Alignment Data RTI and RIS</td>
<td>9.2</td>
<td>Direction cosine rotation matrix RTI between TRCF and HIRDLS IRCF.</td>
<td>Rotation matrices RTI, RIS</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<td>9.3</td>
<td>Direction cosine rotation matrix RIS between HIRDLS IRCF and SRCF.</td>
<td>Rotation matrices RTI, RIS</td>
<td>At SS level</td>
<td>Done</td>
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## Calibration Requirements

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<tr>
<td>9</td>
<td>2.8.3.1</td>
<td>Alignment Data for Scan Mirror</td>
<td>9.4</td>
<td>Direction cosine rotation correction matrices R\text{CE} and R\text{CA} specifying the effective rotation axes of the gimbal in the relevant frames of ref.</td>
<td>Rotation matrices and vectors</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<td></td>
<td>9.5</td>
<td>Directions of the POA V\text{b} and field rotation datum V\text{r} rays incident upon the scan mirro as vectors in the TRCF.</td>
<td>Rotation matrices and vectors</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<td>10</td>
<td>2.8.3.2</td>
<td>Scan mirror position as fcn of telemetry</td>
<td>7.1</td>
<td>Calibration algorithms for elevation angle encoder.</td>
<td>Calibration algorithm for mirror az., mirror el., and wobble sensors</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<tr>
<td></td>
<td>&amp; 2.7.5</td>
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<td>7.2</td>
<td>Calibration algorithms for azimuth angle encoder.</td>
<td>Calibration algorithm for mirror az., mirror el., and wobble sensors</td>
<td>At SS level</td>
<td>Done</td>
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<td>7.3</td>
<td>Calibration algorithms for wobble sensors.</td>
<td>Calibration algorithm for mirror az., mirror el., and wobble sensors</td>
<td>At SS level</td>
<td>Done</td>
<td>Done</td>
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<tr>
<td><strong>FOV</strong></td>
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<td>6.1</td>
<td>2D field response profile for each channel, at various instr and detector temps.</td>
<td>CHILOS az and el offsets wrt ILOS</td>
<td>At instr level</td>
<td>Done</td>
<td>First Look</td>
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</tbody>
</table>

HIRDLS Delta PSR – Oxford University
21 November 2002
Closure 7.17
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<td><strong>FOV</strong></td>
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<td>12</td>
<td>2.6.3.1 &amp;</td>
<td>IFOV wrt ILOS for each channel</td>
<td>6.1</td>
<td>2D field response profile for each channel, at various instr and detector temps.</td>
<td>FOV function for each channel, OOF responses</td>
<td>At instr level</td>
<td>Done</td>
<td>First Look</td>
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<td>2.6.2.1</td>
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<td>6.2</td>
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<td>2D field response profile for each channel, at reduced spatial resolution and increased sensitivity to search for any small OOF responses.</td>
<td>FOV function for each channel, OOF responses</td>
<td>At instr level</td>
<td>Done</td>
<td>First Look</td>
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<tr>
<td><strong>SPECTRAL</strong></td>
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<tr>
<td>13</td>
<td>2.4.2 &amp;</td>
<td>Spectral bandpass for each channel</td>
<td>5.2</td>
<td>Relative spectral response profile for each channel passband down to the 0.2% level, under various conditions of optical bench and detector temp.</td>
<td>Spectral fcn for each channel, out-of-band responses</td>
<td>At instr level</td>
<td>In progress</td>
<td>First Look</td>
</tr>
<tr>
<td></td>
<td>2.4.4</td>
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<td>5.3</td>
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<td>Out-of-band response down to 0.01% level, under various conditions of optical bench and detector temp.</td>
<td>Spectral fcn for each channel, out-of-band responses</td>
<td>At instr level</td>
<td>Done</td>
<td>Quick Look</td>
<td></td>
</tr>
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<td>14</td>
<td>2.5.3</td>
<td>Noise for each channel</td>
<td>4.4</td>
<td>Background scan while EBB temp ramped over whole range in order to measure NEN at all input radiance levels.</td>
<td>Baseline set of NEN for each channel</td>
<td>At instr level</td>
<td>Done</td>
<td>First Look</td>
</tr>
</tbody>
</table>
Closure

Pre-launch Calibration Status

- Data Acquisition – 99% complete
- Data Analysis
  - Quick look: 75% complete
  - First look: 25% complete
  - Detailed: 10% complete
- Remaining tasks (as of Nov 18)
  - 2d orbital sim – 55% complete
  - 1d calibration benchmark measurements
  - 18h FP3, WF2, side-B = linearity & radiometry
  - 3d FP3, WF2 = in-band spectral
  - 48h FP3, WF2 = out-of-band spectral
  - 24h FP3, L2, WF2 = FOV maps
  - 12h FP3, WF2, L2 = Linearity & Radiometry
  - 1d Calibration benchmark measurements
  - 1d Data Review
  - 3d Warm-up/Vent
  - 1d Remove from chamber
  - 1d BAT
  - 2d Pack
  - 3d Ship to TRW