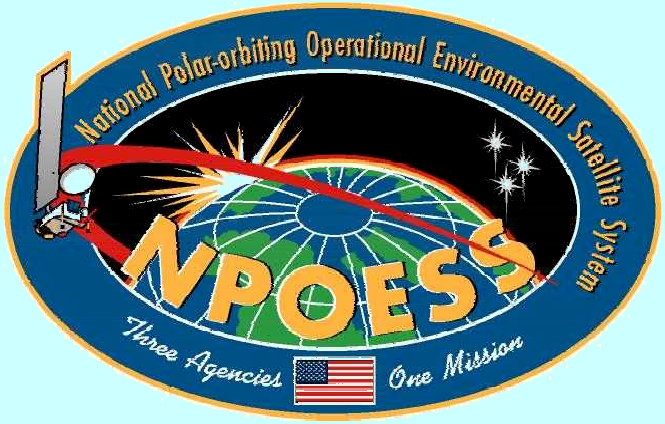


CrIS Sensor: Generation of RDRs and SDRs

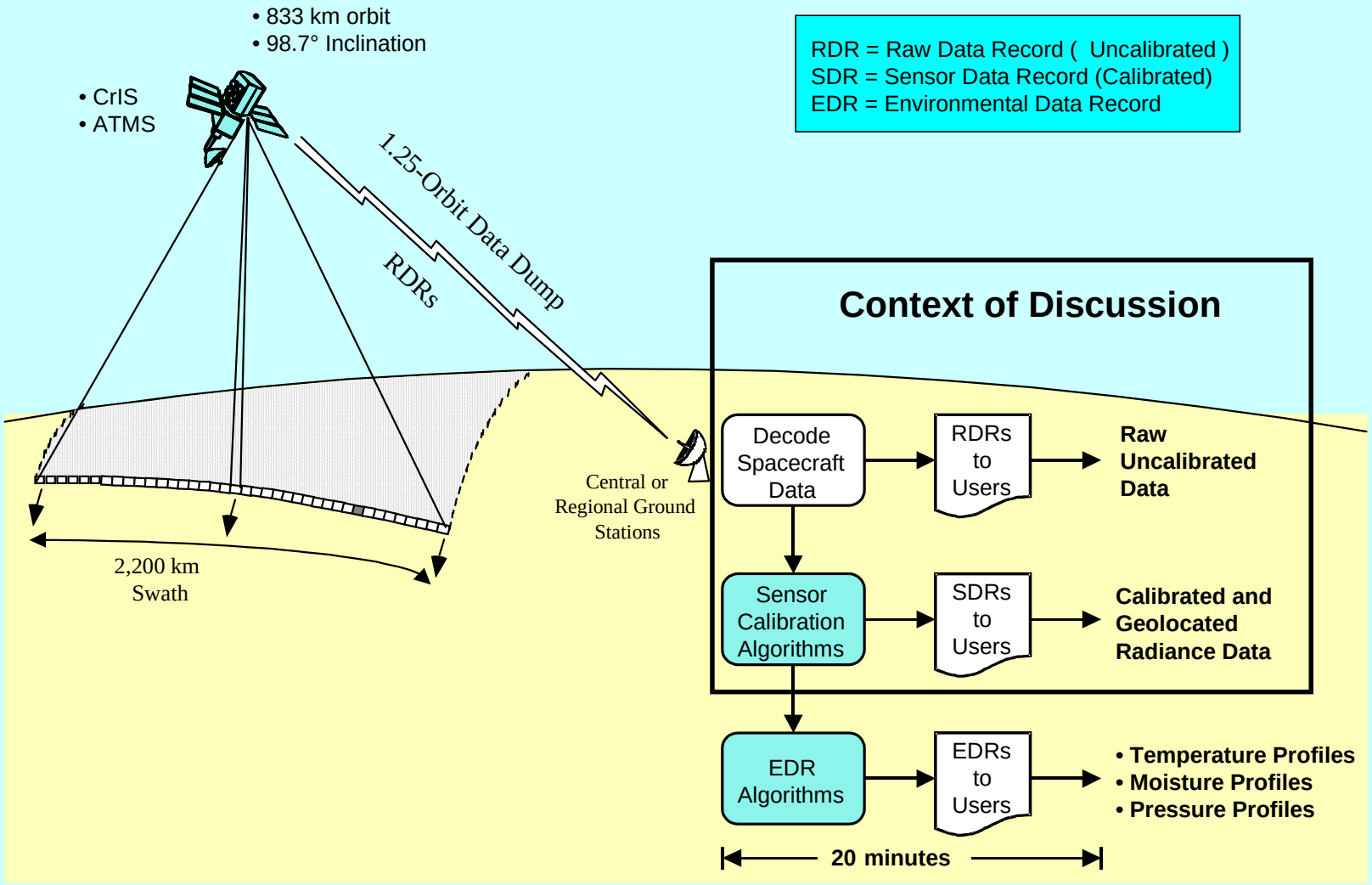
R. Glumb & J. Predina

ITT Industries, ITT Aerospace/Communications,
1919 West Cook Road, P.O. Box 3700, Fort Wayne, IN 46801, USA

Contact: ron.glumb@itt.com

Contact: joe.predina@itt.com

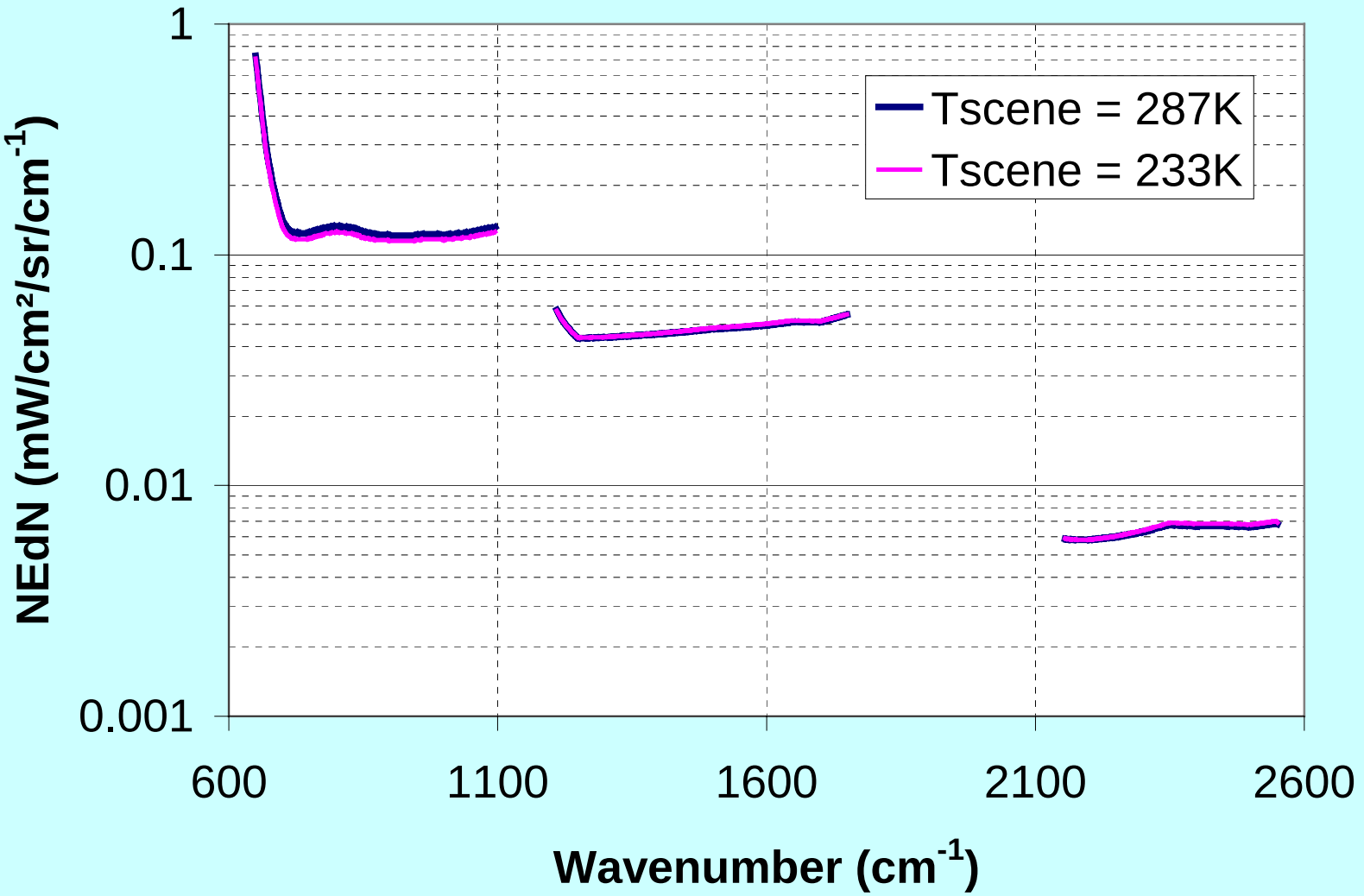
Overall Relationship of RDRs, SDRs and EDRs



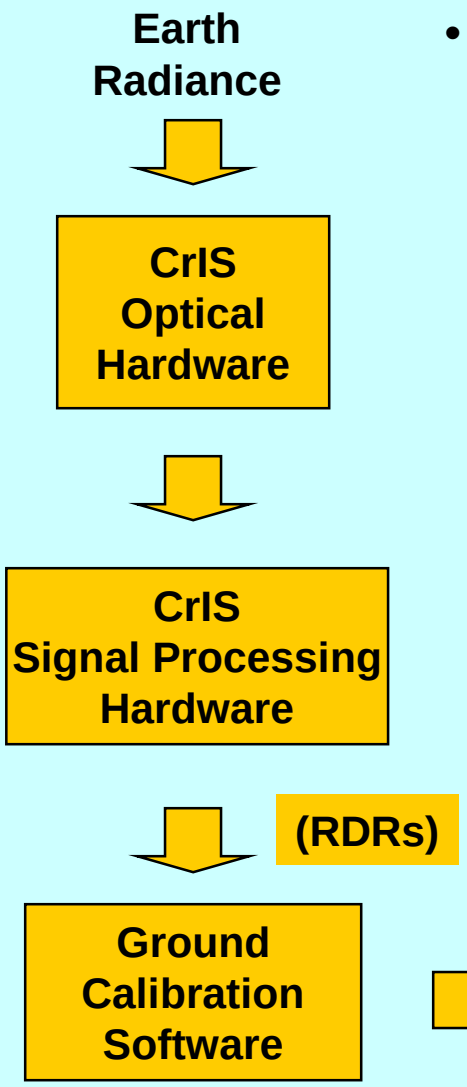
CrIS Science Mission Cardinal Requirements

Reqmnt ID	Requirement	LWIR	MWIR	SWIR
SDRP907	Spectral Bands	650 – 1095 cm^{-1}	1210 – 1750 cm^{-1}	2155 – 2550 cm^{-1}
SDRP944	Unapodized Spectral Resolution 1/(2*max OPD)	0.625 cm^{-1}	1.25 cm^{-1}	2.5 cm^{-1}
SDRP3546	Spectral Uncertainty	10 ppm (flight unit 1) 5 ppm (subsequent flight units)	10 ppm (flight unit 1) 5 ppm (subsequent flight units)	10 ppm (flight unit 1) 5 ppm (subsequent flight units)
SDRP6841	ILS Shape Uncertainty	0.5% FWHM	0.5% FWHM	0.5% FWHM
SDRP3481	Radiometric Uncertainty	0.45%	0.58%	0.77%
SDRP1033	System NEdN	See Chart	See Chart	See Chart
SDRP3696	FOV Size (km) - 70% width (in/x track) - 50% width (in/x track) - 10% width (in/x track) - 1% width (in/x track)	 11.8/12.7 13.2/14.2 14.9/16.0 16.8/18.0	Same as LWIR	Same as LWIR
SDRP3696	FOV Shape Match (km) - 70% width - 50% width - 10% width - 1% width	 0.3 0.2 0.3 N/A	 0.3 0.2 0.3 N/A	 0.3 0.2 0.3 N/A
SDRP3628 SDRP3630	Scan Extent	30 x-track FORs: +/- 48.333^{o}	30 x-track FORs: +/- 48.333^{o}	30 x-track FORs: +/- 48.333^{o}
SDRP882	Mapping Uncertainty	1.5 km	1.5 km	1.5 km
SDRP3731	LOS Jitter	50 μrad/axis	50 μrad/axis	50 μrad/axis

CrIS Science Mission Cardinal Requirements: NEdN



Signal Flow



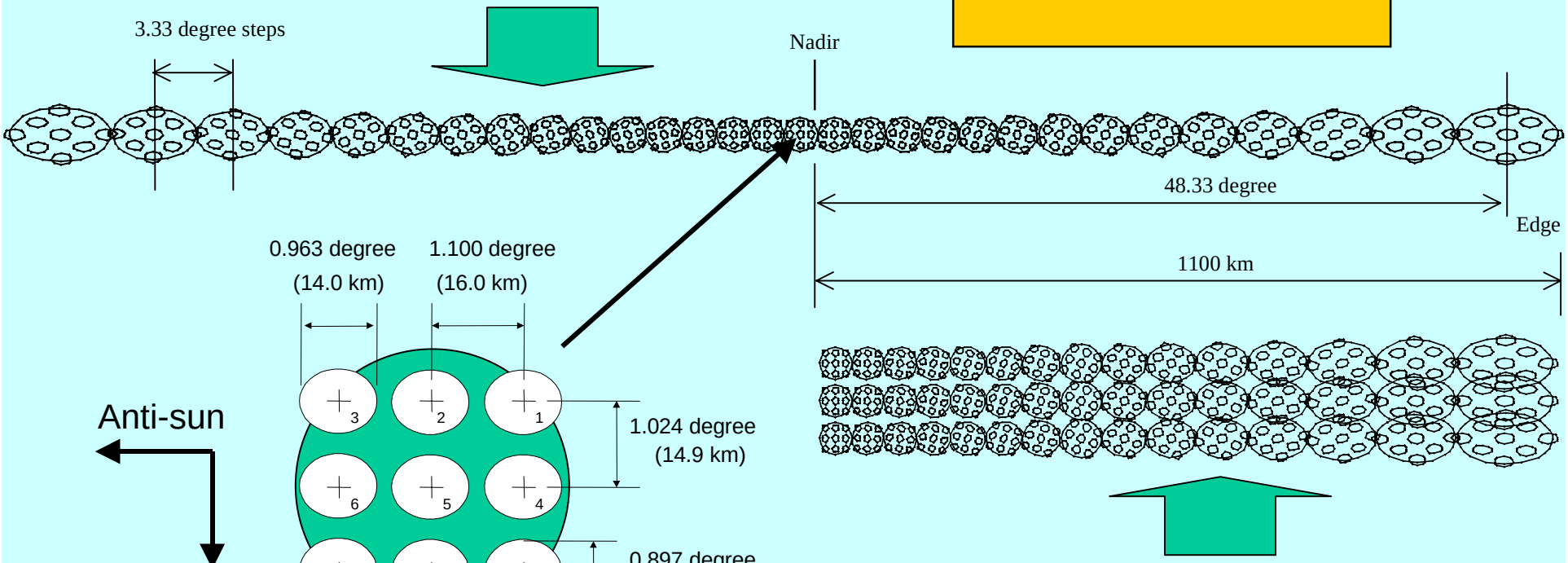
CrIS System Functional Partitions for Generation of SDRs

- **CrIS SDR System Is Comprised of**
  - **Optical Processing Hardware**
    - Converts Scene Radiance to Photons at Detector Surface
    - 9 separate FOVs with three colors in each
  - **Electronic Signal Processing Hardware**
    - Converts Photons at 27 Detector Surfaces into uncalibrated sampled data streams out of instrument (RDRs)
  - **Ground Calibration Software**
    - Converts Raw Data Records (RDRs) to Calibrated Sensor Data Records (SDRs)
      - Each FOV Geo-located
      - 1305 Spectral Channels (colors) per FOV
      - Radiometrically calibrated
      - Spectrally calibrated

Optical Signal Flow: Earth Scene Interrogated with 3x3 FOV Array

CrIS Field of Regard (FOR) Definition
- 1 FOR = 9 FOVs
- 1 FOV = 3 IR bands

Single CrIS Scan Line
(full sweep, 30 FORs)



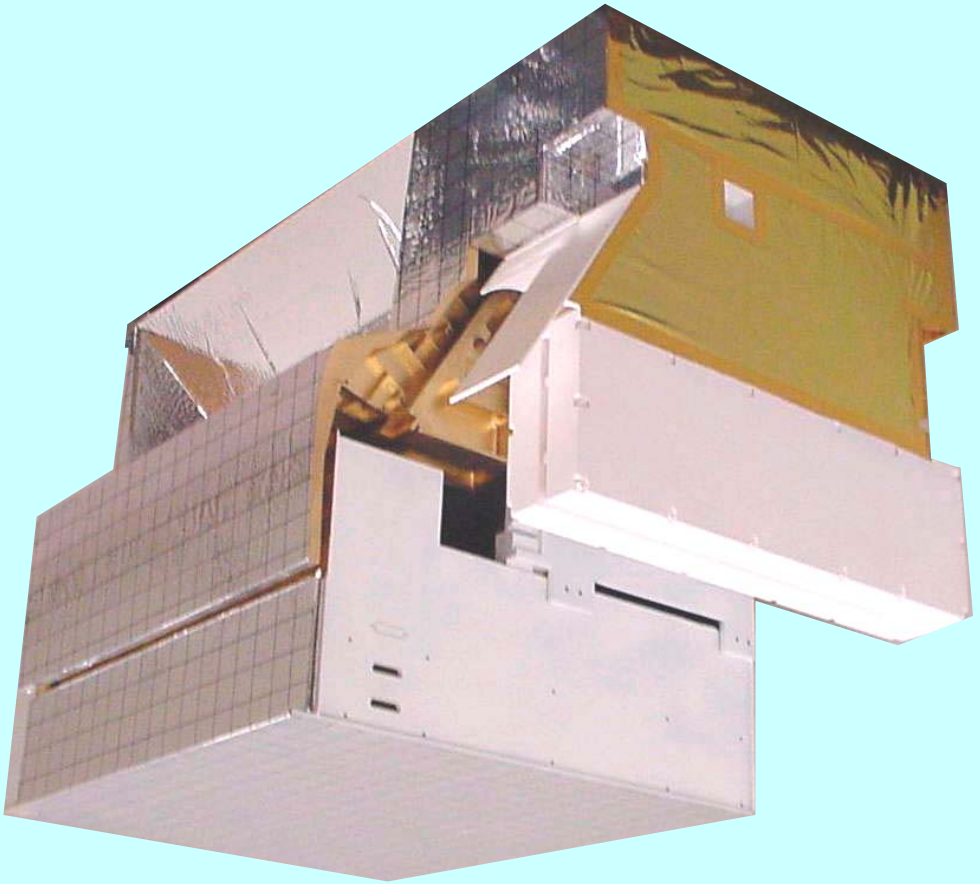
Three Successive CrIS Scan Lines
(nadir to edge sweep)

Signal Flow

Instrument Converts Scene Photons to Packetized Bits (RDRs)

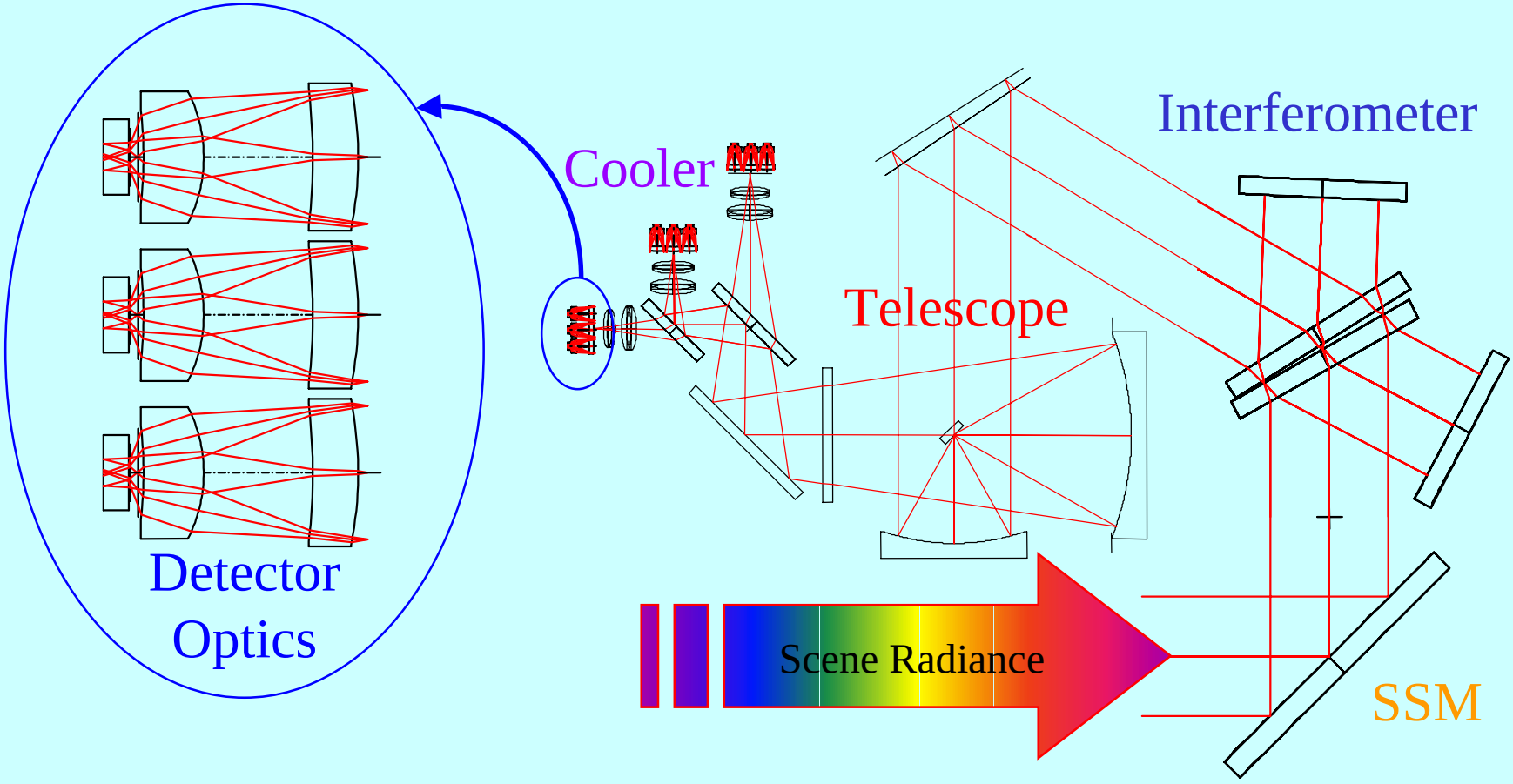
Optical Signal Flow: Entrance Pupil to Exit Pupil

Electrical Signal Flow: Exit Pupil to Packetized Bits



Optical Signal Flow: Entrance Pupil to Exit Pupil

- **Partially unfolded CrIS optical system shows flow of signal radiance to detectors.**

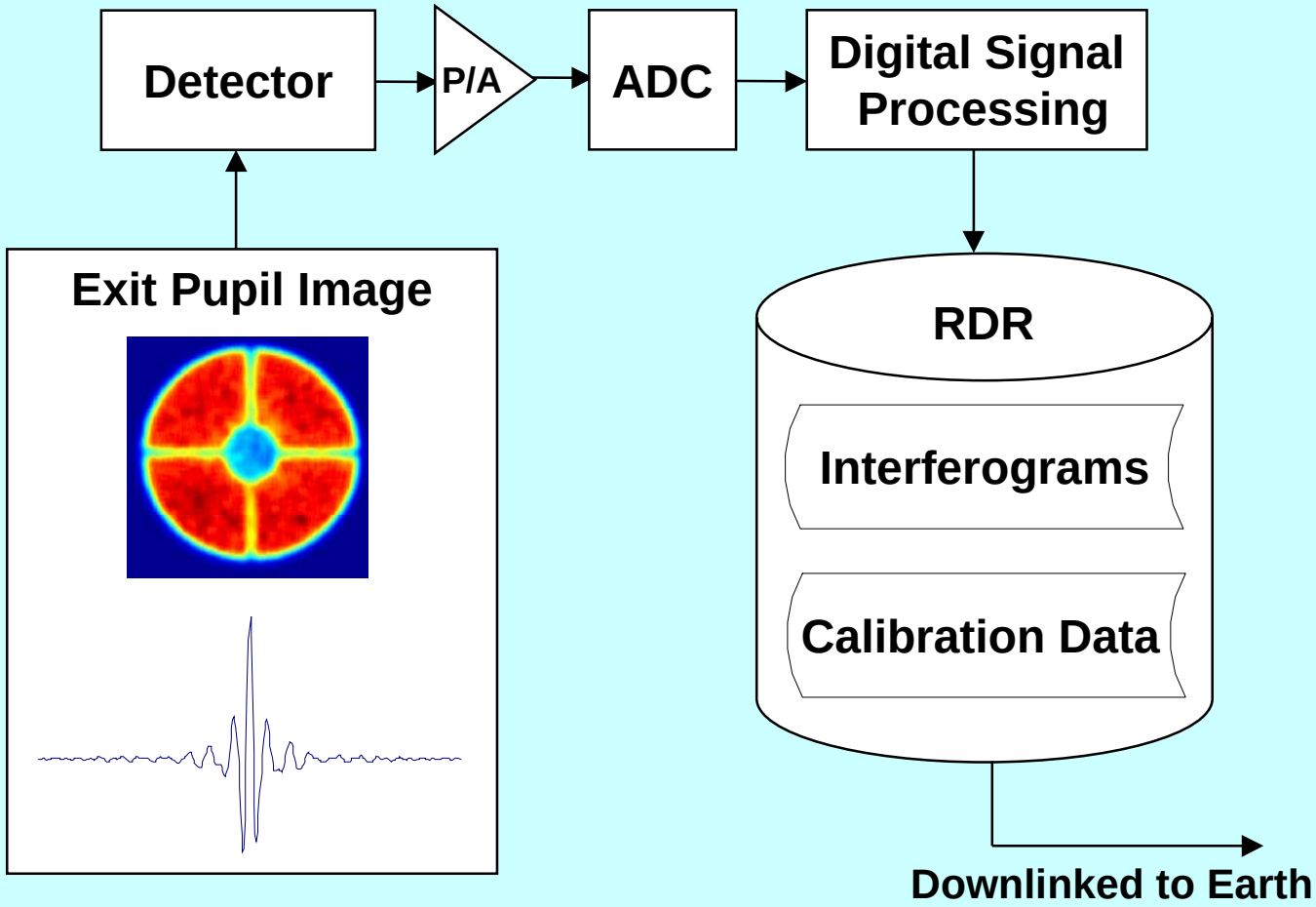


Optical Signal Flow

Electrical Signal Flow: Pupil Image Photons to Packetized Bits

Detector Active Area Plane Located at Exit Pupil

RDR Consists of:
- **Engineering Data**
- **Science TLM Data**
- **Signal ID/QC Data**



Optical Signal Flow

Interferogram Generated by Interferometer With +/- 0.8 cm OPD Sweep

Double-sided Interferograms Baselined for CrIS

Double-Sided Interferogram Benefits:

- Better phase calibration of instrument (and consequent treatment of channelization effects)
- Less sensitive to sweep asymmetries of hardware (vs Single-sided interferograms)

Electrical Signal Flow

Filters Optimized for Low Gain and Phase Distortion

Dedicated A/D on Each Channel Minimizes Noise

Digital Processing Techniques Significantly Reduce Data Transmission Rate

Extensive On-orbit Programmable Flexibility

CrIS Electronic Signal Processing: Key Features (1 of 2)

- **27 Channel Interferogram Signal Processing**
  - **Anti-alias analog filter**
    - 5 pole low pass (51.7 kHz)
    - 2 pole high pass (300 Hz)
  - **14-bit ADC**
    - 13.4 effective bits on each detector channel @ 128 ksps
      - Oversampled to prevent cut-off effects of anti-aliasing filter (gain/phase slope) from encroaching IR signal passband
    - Metrology delay matched sampling, commandable
  - **Programmable electronic gain**
    - Optimizes each CrIS IR channel dynamic range
    - 40 dB range, 0.156 dB increments, commandable
  - **Impulse noise suppression**
    - Reduces impulse noise energy over 60 times, programmable
  - **255 tap decimating digital FIR filter (fully programmable)**
    - Decimation reduces bandwidth & data rate
    - 69 dB stopband, +/-2.5 dB In-band ripple, sharp transition
    - 9 channel ASIC implementation for low power & speed
  - **Bit trim encoding to reduce data rate**
    - Removes unneeded leading zeros of interferogram data samples
    - Implemented by Flight computer, commandable reconfigure

Electrical Signal Flow

CrIS Electronic Signal Processing: Key Features (2 of 2)

CrIS Formats All Data into CCSDS Packets

- **Data transmitted in Packets with Unique IDs**

- **Science Data Channel (packets per 8 second scan)**
  - **Earth scene packets (810 = 27 detectors x 30 scenes)**
  - **ICT calibration packets (54 = 27 detectors x 2 looks)**
  - **DS calibration packets (54 = 27 detectors x 2 looks)**
  - **Science telemetry packet (1)**
  - **Engineering packet (once every 30 scans, 4 minutes)**

Yields 1.44 Mbps Data Rate

Packets Tagged with Unique APIDs to Speed Sorting and Ground Processing

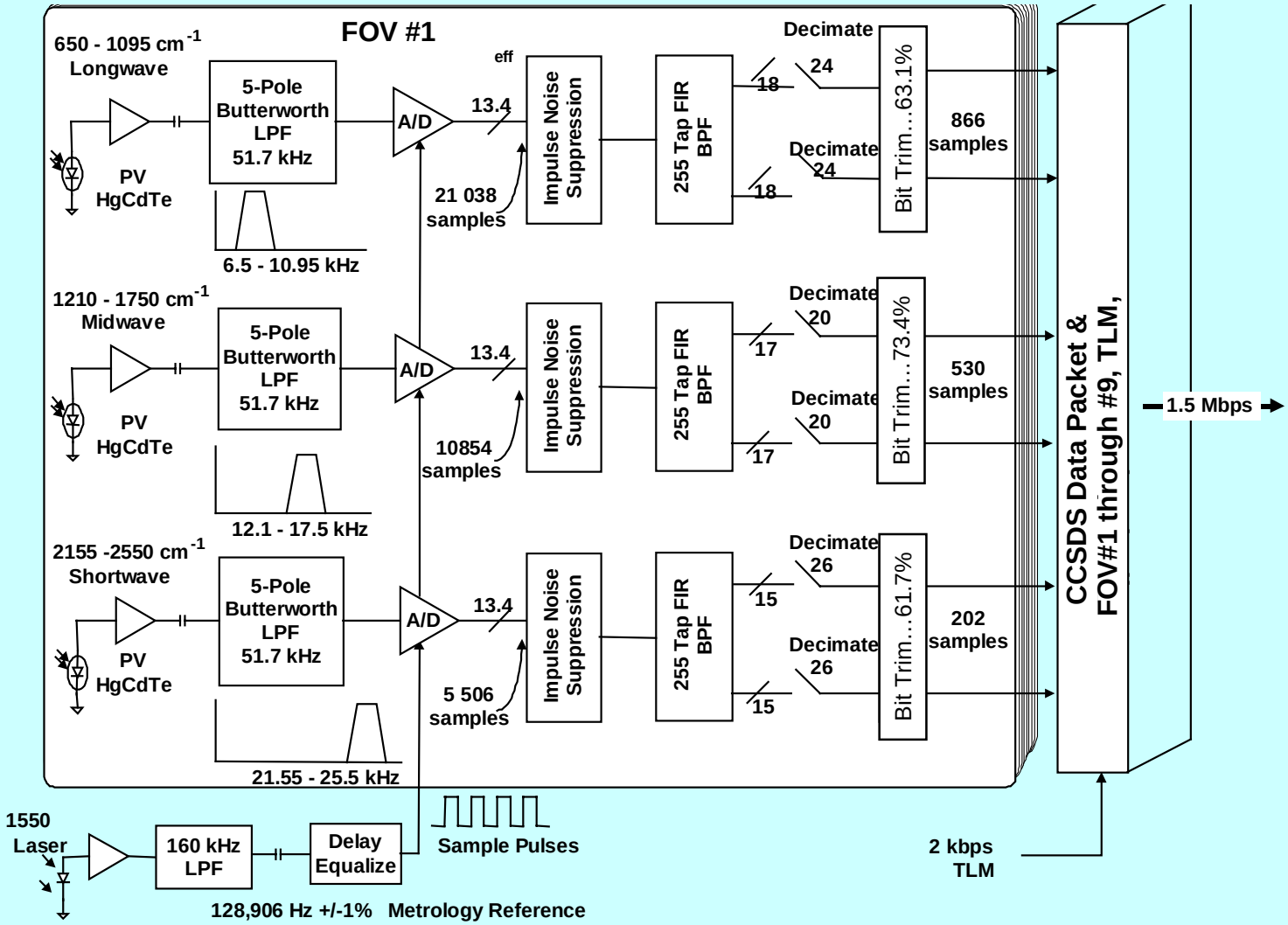
- **Other Data Packets for C&DH, Diagnostics**
  - **Time of Day (TOD) & navigation packet (once/sec)**
  - **Housekeeping telemetry (2 kbps)**
  - **LEO&A telemetry (0.256 kbps)**
  - **Command packets**
  - **Test packets**
  - **Memory load/memory dump packets**
  - **Diagnostic interferogram data packets**
  - **Telemetry dwell packets (diagnostic telemetry)**

Up to 128 Unique APID Packet Assignments

Electrical Signal Flow

CrIS On-board Signal Processing Builds RDRs

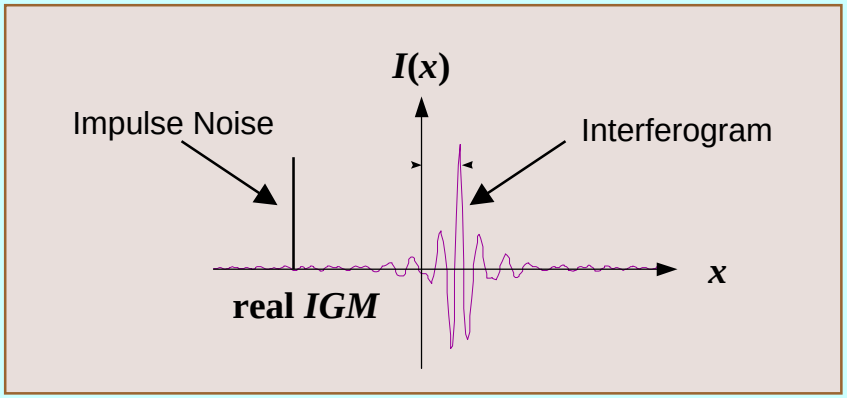
- 10 cm/sec OPD Sweep Velocity
- 1% Sweep Velocity Error
- 160 msec Integration Time
- Laser Metrology Driven Sampling
- IR to Metrology Delay Matching
- Impulse Noise Suppressed
- Low Data Rate



Electrical Signal Flow

Impulse Noise Detection/Suppression is Important in a Space Environment

- **CrIS Detectors Can Be Subject to Impulse Noise**
  - **Sensor charging/arc discharge**
  - **High energy particle (space radiation environment) bombardment of detector**
  - **Impulse will span two undecimated interferogram samples**
  - **Frequency of occurrence expected to be very low**



- **Impulse Noise Clipping Reduces Noise Susceptibility**
  - **Factor of 60 or more suppression improvement**
  - **CrIS uses bit trim mask to detect impulse noise prior to digital FIR filter/decimation**
  - **Substitute a zero value in place of the measured impulse noise value.**
  - **Number of impulse noise hits is counted and reported for each interferogram to aid in data quality assessment.**

Electrical Signal Flow

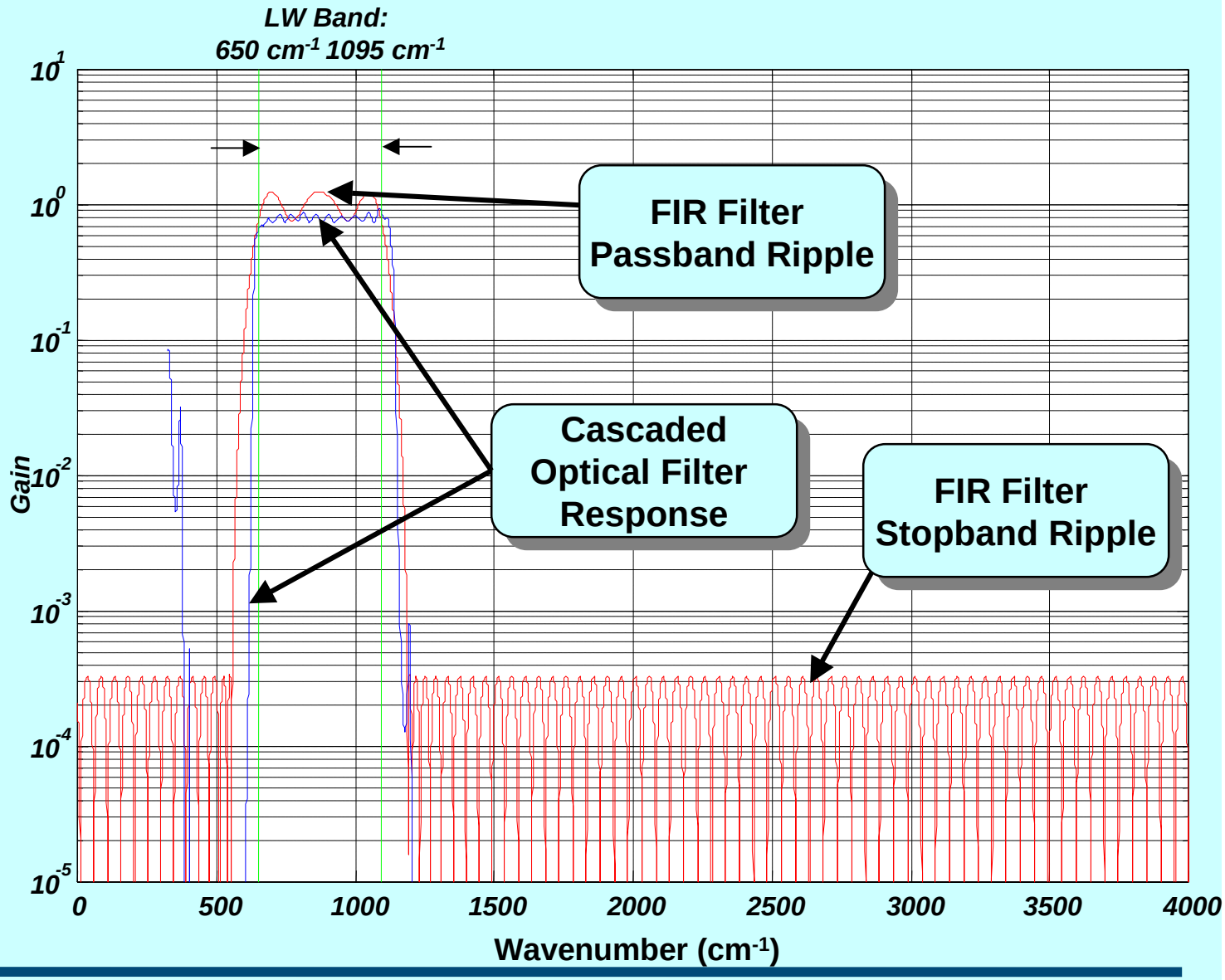
255 Tap Digital FIR Filter & Optical Filter Overlay Long Wave Band

Cascade of Two Optical Filters Plus Sharp Cutoff Digital FIR Filter Provide High Out-of-Band Rejection

Excellent Robustness to EMI Aliasing

Enables Use of Large Decimation Factor

In-band Ripple Removed by Calibration



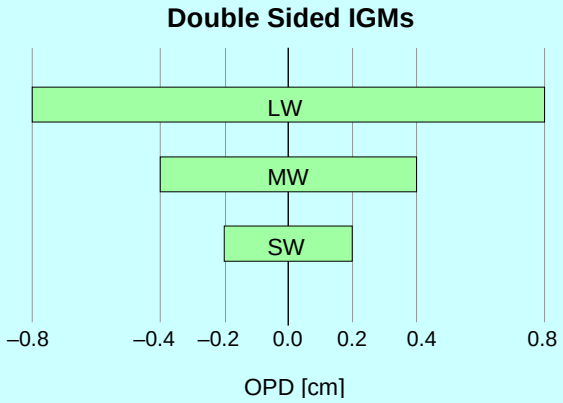
Filtering and Decimation

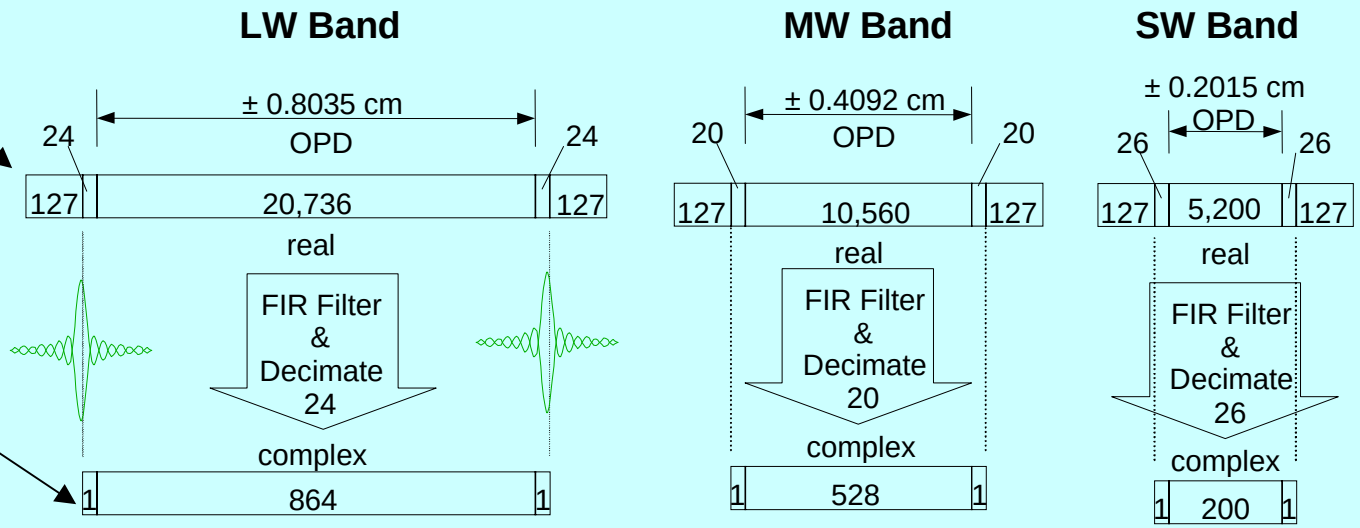
Order of Magnitude Reduction of Samples via Signal Processing

Overscan Samples Taken to Fill Digital FIR Filter Pipeline

One Decimated Overscan Sample for ZPD Uncertainty

CrIS Interferogram Measurements





Electrical Signal Flow

Bit Trimming Performed By CrIS Flight Computer
(LW example for a pre-trimmed 17 bit word width)

Bit Trimming Allows CrIS to Meet Bandwidth Requirements

Bits Above Mask Are Discarded

No Loss of Information

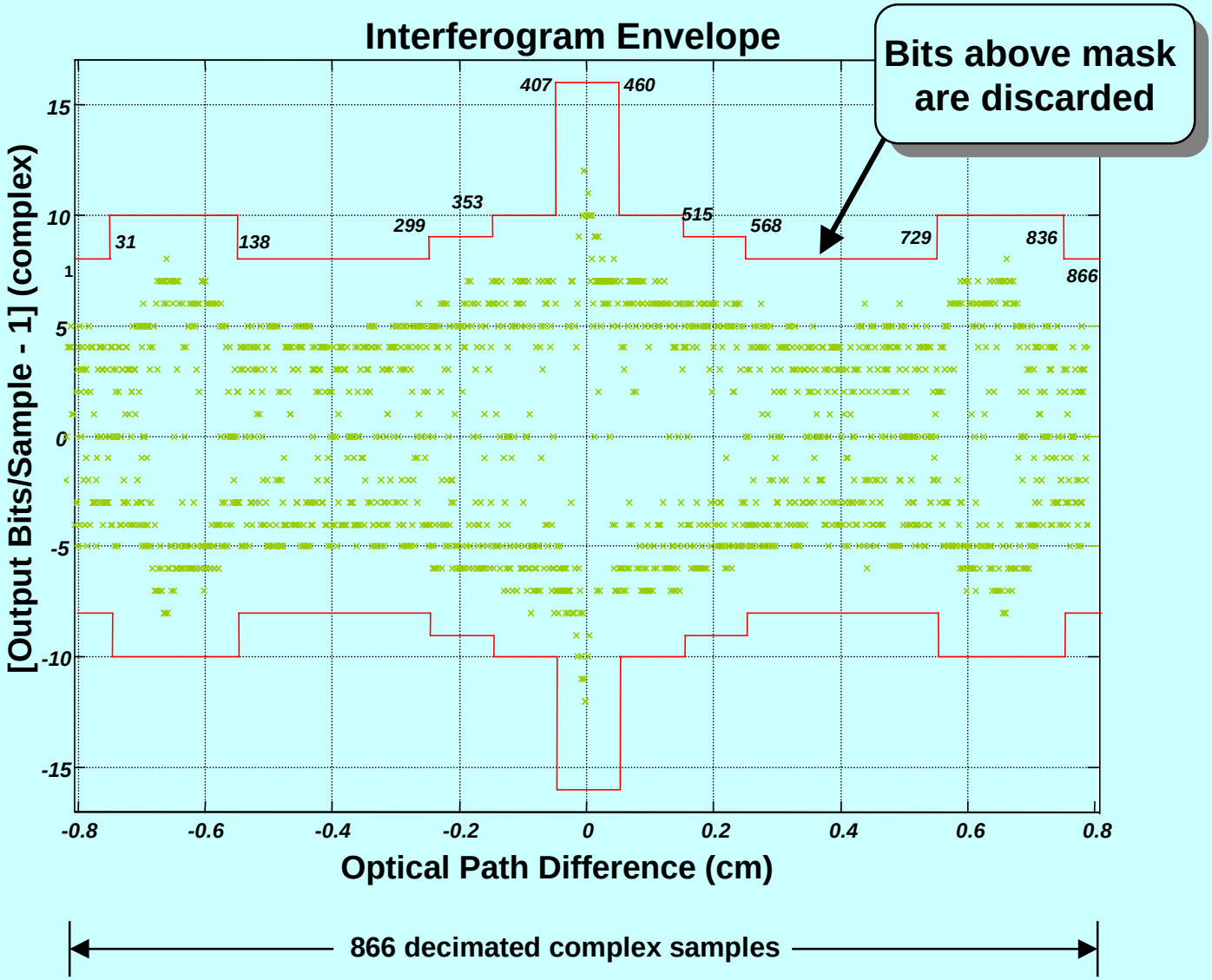
On-orbit Programmable Mask

Data After Trim:

63.1% in the LW

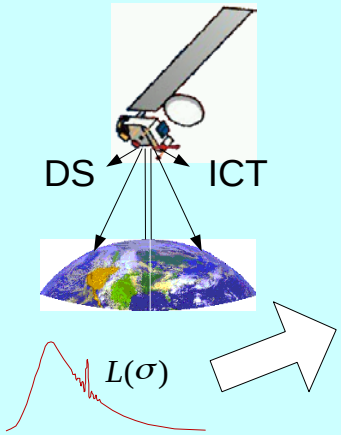
73.4% in the MW

61.7% in the SW



Electrical Signal Flow

Space Segment Processing: Functional Flow



Observed scene
(three different types)

ES: Earth Scene

DS: Deep Space

ICT: Internal Calibration Target

SPACE SEGMENT - CrIS Sensor

Detector → **ADC** → $I(x)$ *real* → **Impulse Noise Clipping**

Must be done first

Interferogram (photons) $I(x)$

255 Tap FIR

Filtering & Decimation

Reduces data rate

$\tilde{I}(x)$ *complex*

Bit Trimming

Packet Encoding

Downlinked to Earth

RDR
- Interferograms
- Calibration Data

Engineering Data

Once per 4 minutes
- Bit trim format data
- laser frequency info: NNe, NL
- ICT emissivity tables & model
- Polarization correction tbl (if needed)
- ILS parameters for 54 channels
- CrIS mounting angles
- LOS angles for each FOV

Signal ID/QC Data
- IGM start time (UTC)
- FOR index (0-31)
- Band ID (LW,MW,SW)
- FOV ID (1-9)
- Sweep direction
- ZPD min, max & position
- Quality control flags
- Impulse noise count

Once per 8 seconds
- Laser diode temperature/current
- ICT, BS, Scan mirror temperatures
- All optic temperature telemetry
- SSM pointing errors

Science TLM Data

Only Processing of Science Data Shown

Electrical Signal Flow	RDR Content (1/3)

Comprises Bulk of Data →

- **Interferogram Data Packets (27 packets/FOR)**
  - **Interferograms**
  - **Interferogram Identifiers**
    - Spacecraft ID tag
    - CrIS Sensor ID or serial number
    - FOR index (1 - 30 = Earth scenes, 0 = ICT, 31 = DS)
    - FOV number (1-9)
    - Band designator (LW, MW, SW)
    - Interferometer sweep direction (forward, reverse)
    - UTC stamp (Instant when FOV footprint frozen)
    - ZPD magnitude and fringe count
  - **Data Quality Indicators**
    - Fringe count error and fail bit trim flags
    - Impulse noise count (0-127)
    - Invalid interferogram data flag (Saturated channel, failed detector)

Auxiliary Data Contained in Each Interferogram Data Packet Used for Identification Purposes

Contaminated Data Detected by CrIS Sensor & Flagged

Electrical Signal Flow

RDR Content (2/3)

Engineering Data Embedded in RDRs Eliminates Need for Sensor Unique Calibration Handbooks

Allows Remote Terminals to Seamlessly Synchronize with Any CrIS Sensor Downlink Anytime

- **Engineering Data Packet (once per 4 minutes)**
  - **Metrology Wavelength Data**
    - Neon fringe count (from last calibration)
  - **ICT Calibration Data**
    - Emissivity versus wavenumber
    - ICT radiometric model parameters
  - **ILS Model Parameters for Each CrIS Detector**
    - FOV to LOS offset angles
    - FOV size (angular)
  - **Polarization Correction Data vs. Scan Angle & Wavenumber**
  - **Mapping Data**
    - CrIS to S/C alignment cube
    - CrIS LOS to CrIS cube reference angles
    - CrIS scanner to interferometer alignment data
  - **Coefficients to convert data to engineering units**
  - **Bit trim parameters & other format decoding data**

Electrical Signal Flow

RDR Content (3/3)

Science Telemetry Packets Only Contain Dynamic Data Supporting Science Mission Calibration and Geolocation

- **Science Telemetry Data Packet (once per 8 seconds)**
  - **Metrology Wavelength Data**
    - Laser diode case temperature, current and model parameters
  - **Temperatures**
    - Beamsplitter, Scan mirror, Scan Baffle, Telescope, Aft optics, Detector
  - **SSM servo pointing errors**
    - From each of 30 previous earth scenes
    - In-track
    - Cross-track

More Complete and General Telemetry/House keeping Data Sent to Spacecraft Operations Control Center Over Different Channel

- **Normal Telemetry Data Packets (once per second)**
  - **Rotation of 8 fixed format packets**
    - 2 kbps maximum data rate
    - Recent FT1394 requirement
  - **Contents**
    - Temperatures, secondary voltages, PCE status, command status, heater currents, IFM status, SSM status

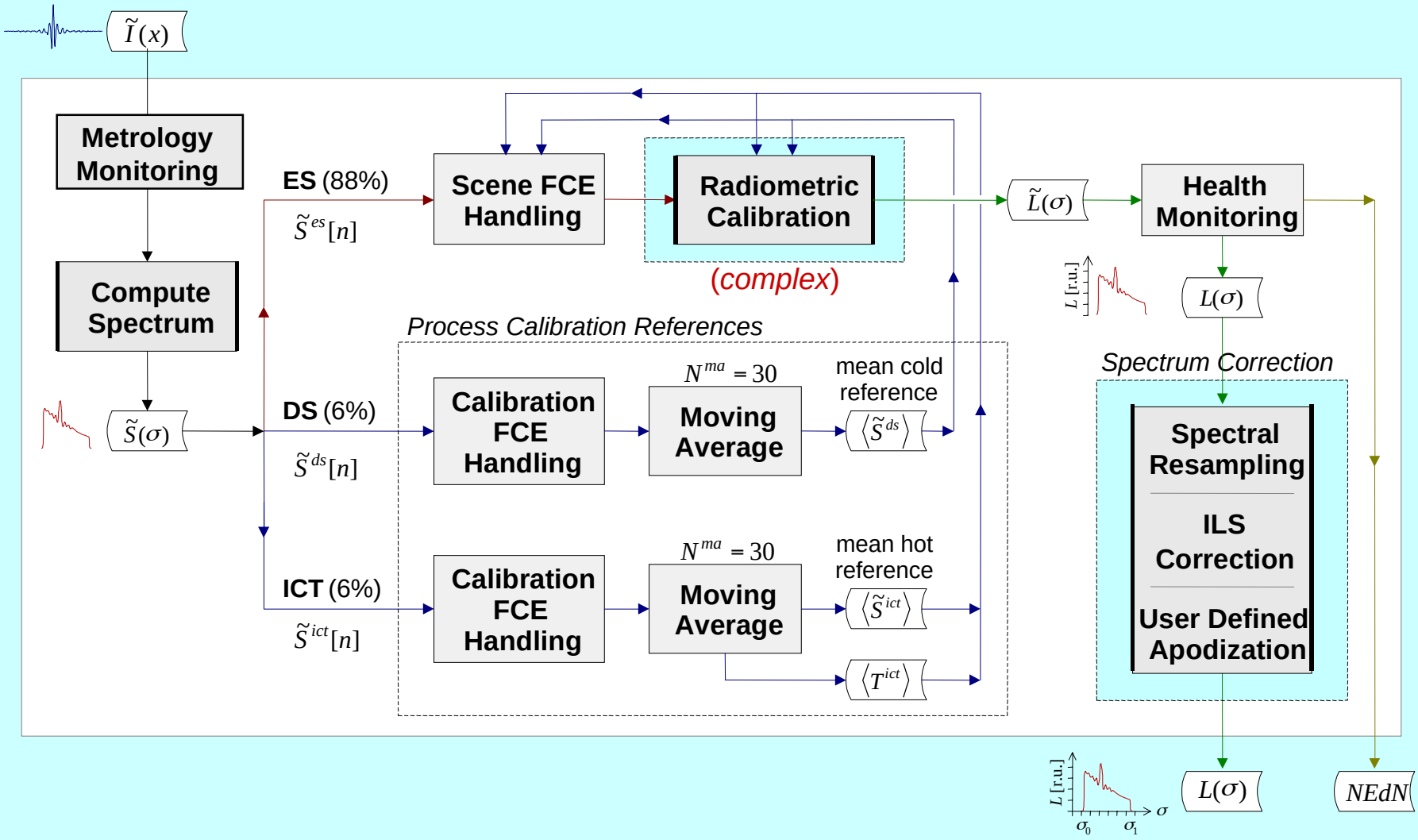
SDR System Design Description: Ground Software Element

Ground Calibration Software Is Partitioned into 9 Modular Groups

- **Initialization**
  - **Initialize software**
  - **Initialize RDR reading pointers**
- **Data Input**
  - **Low level data handling**
  - **Configuration data handling**
  - **Calibration data handling**
    - Ingest sensor unique cal data
    - Monitor calibration data
    - Compute spectrum correction matrix
  - **Science data handling**
- **Geolocation**
  - **Map FOV to latitude & longitude**
  - **Calculate view angles/ footprint geometry**
- **Preprocessing**
  - **Perform bit trim decoding**
  - **Convert interferograms to spectra**
- **Spectral Calibration**
  - **Perform spectral calibration**
  - **Compute laser WL from neon lamp**
  - **Compute laser WL from diode parameters**
- **Radiometric Calibration**
  - **Average warm target spectra**
  - **Average cold target spectra**
  - **Subtract sensor background radiance**
  - **Calibrate sensor gain**
  - **Remove phase dispersion**
  - **Compute ICT radiance**
  - **Isolate/reject orthogonal noise**
  - **Apply spectrum correction matrix**
    - Remove ILS errors
    - Apply user selectable apodization
    - Map channels to fixed wavenumber grid
- **Quality Control**
  - **Identify/exclude bad data**
  - **Detect/correct fringe count error**
  - **Estimate NEdN (bin by bin)**
  - **Flag bad FOVs**
- **Post-processing**
  - **Select user required spectral bins**
  - **Format data for EDRs**
  - **Archive data**
- **Data Output**

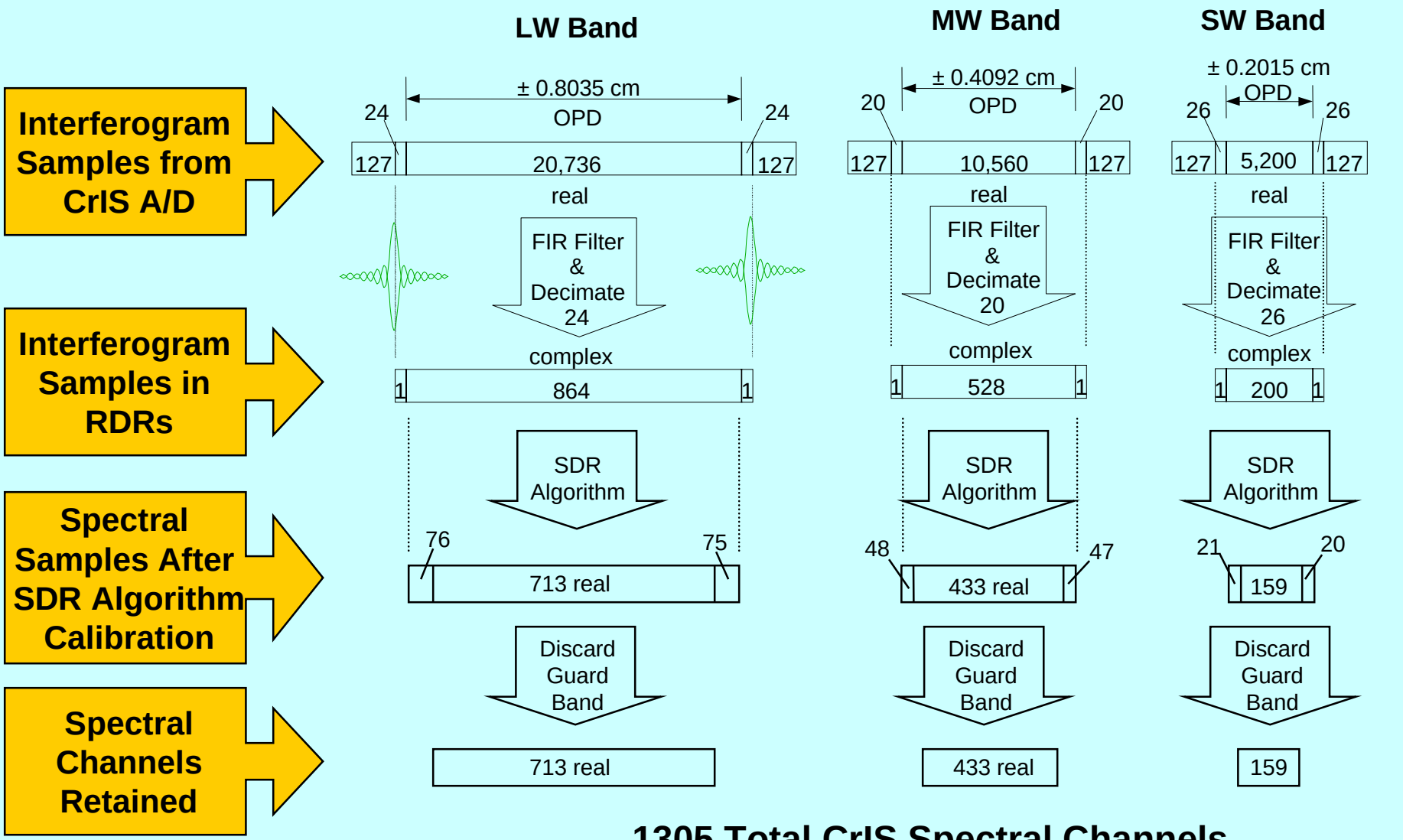
SDR Algorithm

Signal Flow Through Ground Calibration Algorithm



SDR Algorithm

CrIS Interferograms to Calibrated Spectra: Signal Processing Progression



1305 Total CrIS Spectral Channels

SDR Algorithm	SDR Content At SDR Algorithm Output (1 of 2)
Calibrated Radiance in 1305 Channels	• **Calibrated Data** – **Real part of the spectra after Spectral Correction** • LW 713 bins @ 0.625cm-1 (650-1095) • MW 433 bins @ 1.25cm-1 (1210-1750) • SW 159 bins @ 2.5cm-1 (2155-2550) – **Imaginary part of the spectra before Spectral Correction (LW 713 bins, MW 433 bins, SW 159 bins)** – **NEdN estimates (LW 713 bins, MW 433 bins, SW 159 bins)**
Noise Estimates in Each Channel	
Mapping Data	• **Geolocation Data** – **Latitude/longitude @ sea level for each FOV center** – **Major and minor elliptical footprint size for each FOV** – **Elevation & azimuth angle from each FOV center to satellite**

SDR Content At SDR Algorithm Output
(2 of 2)

Identifiers Help in the Archiving of Data

- **Identifiers**
  - Spacecraft ID, CrIS sensor ID, Sensor flight software version number, SDR algorithm version number, Apodization tag
  - FOR number, FOV number
  - Band designator (LW,MW,SW), FOV longitude and latitude, Slant angle, Viewing angle, Size of FOV on ground

Quality of Data Is Assessed and Tagged

- **Quality Control**
  - ZPD reset, Fail bit trim, Impulse noise count (0-127)
  - Invalid data (RDR and SDR) and invalid geolocation flags
  - FCE detected and corrected in SDR algorithm
  - Excess NEdN, Excess Sensor Thermal drift

Web Site

Further Information

- **This presentation of CrIS data record generation and processing is a summary of more detailed information available at:**

http://npoesslib.ipo.noaa.gov