



Common Instrument Interface (CII) Data Interface Guidelines

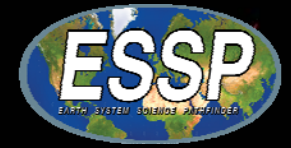
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CII Team

21 April 2011



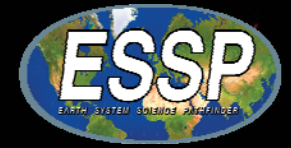
Data Interface Design Goals



- The CII guidelines are provided to increase instrument compatibility with spacecraft so that the maximum number of Missions of Opportunity (MoO) can be realized
- Low-power, high data rate interface
- Lightweight protocol
- Leverage existing standards and practices as much as practical
- Minimally intrusive to spacecraft provider and instrument designer



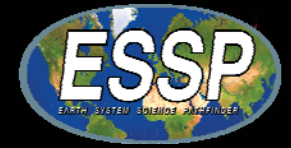
Data Interface Principles



- Rideshare opportunities are maximized when the instrument is autonomous
 - For example, the instrument includes an onboard processor and its own capabilities for packet processing, telemetry monitoring, command and data handling, data storage, compression, playback, etc.
- Protocol provides for instrument commanding, engineering telemetry, and science data
- All data exchanged between the instrument and spacecraft is discrete (digitized) packet data
- Reuse industry standard CCSDS headers for packet control and time tagging



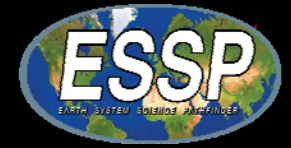
Data Interface Principles



- High-level instrument state (e.g. major mode) is communicated at regular intervals (e.g. in a standard packet header).
- Folding time synchronization and key engineering readbacks into the data protocol eliminates the need for additional physical interfaces (e.g. 1 PPS, discrete lines)
 - May change once instrument and spacecraft are paired
- Most data from the instrument to the spacecraft is opaque, exceptions:
 - The spacecraft may need to command instrument to SAFE mode
 - The spacecraft may need to monitor key instrument engineering data
- Reliable data transmission is accomplished through CRCs, acknowledgements, and expected response times.



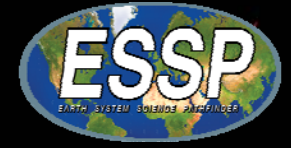
Data Interface Guidelines



- Two dozen guidelines total
- The instrument and spacecraft *should* communicate over a SpaceWire full-duplex point-to-point connection. [Data-01]
- The physical layer and low-level data protocol *should* conform to the ECSS-E-ST-50-12C (SpaceWire) specification. [Data-02]
- The data interface *should* support a common set of commands ... [Data-05]
- The spacecraft *should* receive and forward science telemetry ... [Data-11]
- The instrument *should* packetize and transmit engineering telemetry ... [Data-18]



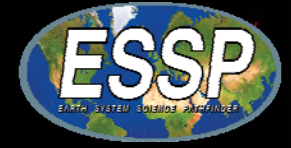
CII Message Types



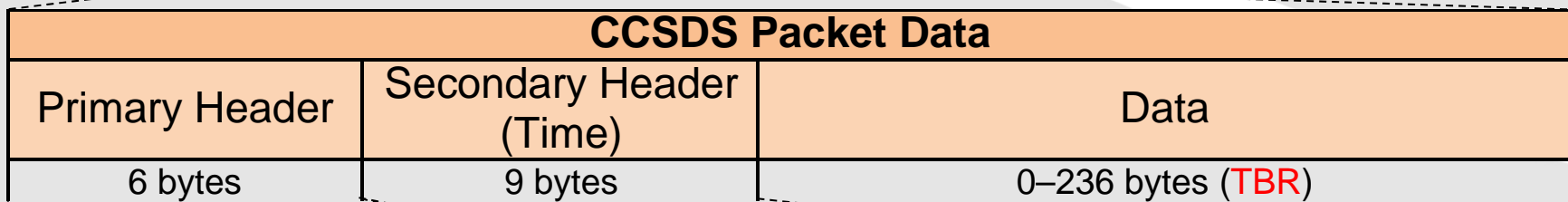
Message	Data Path
Time Message	Spacecraft to Instrument
Ephemeris Message	Spacecraft to Instrument
Command	Spacecraft to Instrument
Command Acknowledgement	Instrument to Spacecraft
Instrument Telemetry	Instrument to Spacecraft
Instrument Science Data	Instrument to Spacecraft



CCSDS Headers



CII SpaceWire Command Packet						
SpW Logical Address	Cargo					ExP
	Protocol ID (0x02)	Reserved (0x00)	Type (0x04)	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	18-251 bytes (TBR)	1 byte	4 bits



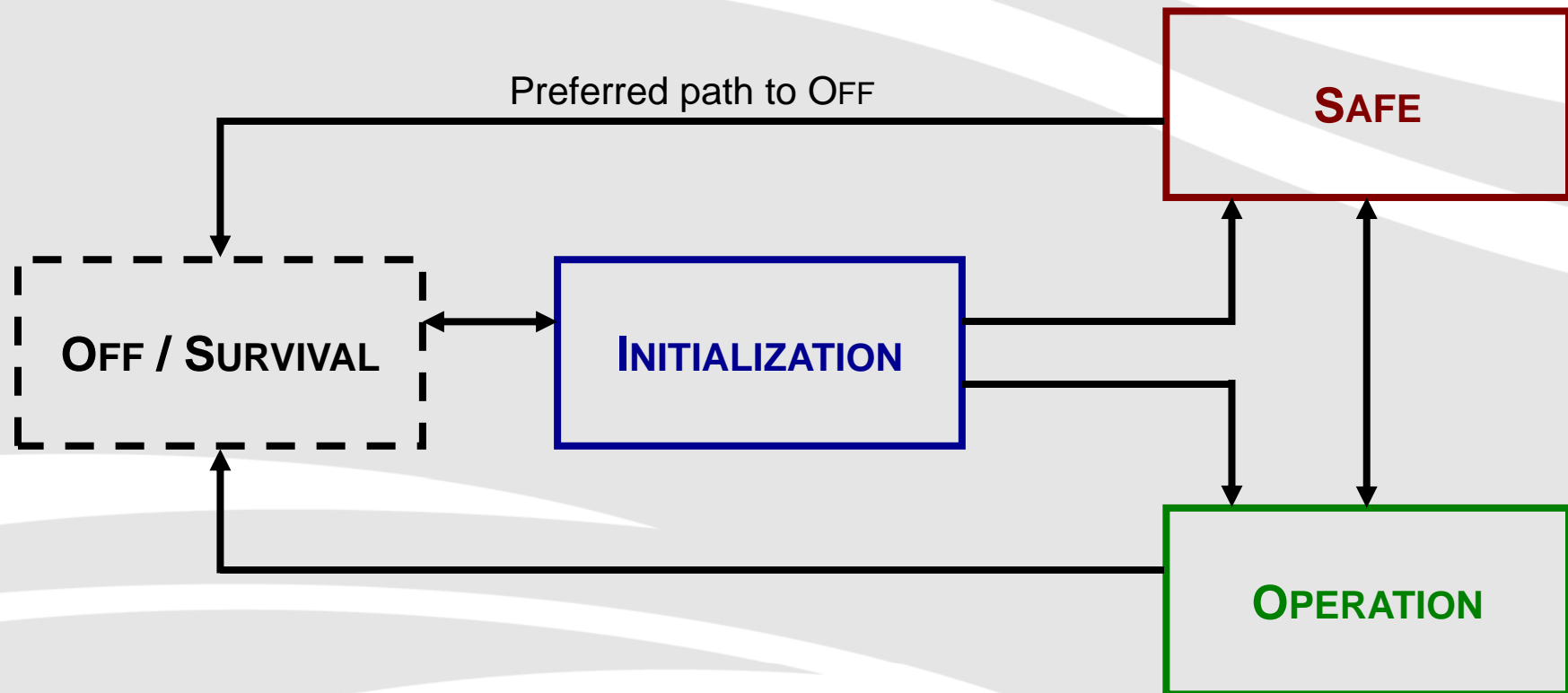
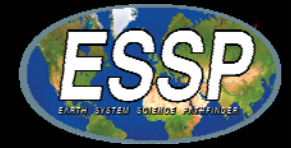
CCSDS Primary Header						
Packet Version Number	Packet Identification			Packet Sequence Control		Packet Length
	Type	Secondary Header Flag	ApID	Sequence Flags	Sequence Count	
3 bits	1 bit	1 bit	11 bits	2 bits	14 bits	16 bits
	2 bytes			2 bytes		2 bytes

CCSDS Secondary Header								
CCSDS Unsegmented Time Code (CUC) Field								
P-Field				T-Field				
Default		Extended		Coarse Time			Fine Time	
1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte

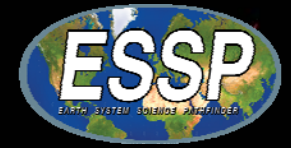
CII utilizes standardized CCSDS header format for information common to all packetized telemetry (e.g. type, length, counters, and time).



Instrument Modes



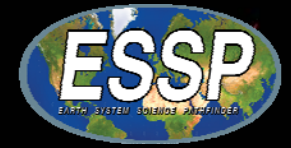
Within the OPERATION mode, instruments *may* define additional sub-modes specific to their operation (e.g. STANDBY, DIAGNOSTIC, MEASUREMENT, etc.).



Reference Protocol (Backup)



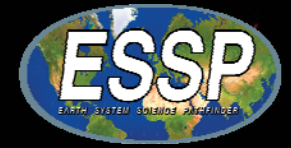
3.1 SpaceWire



- **Cables and connectors**
 - Defined as part of the SpaceWire specification
- **Data Rates**
 - A SpaceWire link clocked at (TBD) Mhz, which provides a useable data rate of (TBD) Mbps (~50–150 Mbps).
 - The instrument *should* receive commands ...
 - The instrument *should* send telemetry and science data ...
- **Time Synchronization (1 PPS)**
 - The instrument *should* receive a low-level SpaceWire time code from the spacecraft once per second.
- **Redundancy (optional)**
 - The instrument *may* employ two SpaceWire links for communication with the spacecraft. The secondary link *should* be used in the event the primary link becomes inoperative or the instrument swaps to second string components.



3.2 CI Packet Types

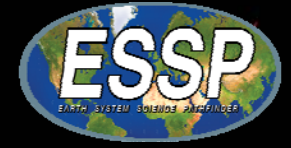


Type Code	Packet Type	Data Path
0x01	Time Message	Spacecraft to Instrument
0x02	Ephemeris Message	Spacecraft to Instrument
0x04	Command	Spacecraft to Instrument
0x08	Command Acknowledgement	Instrument to Spacecraft
0x10	Instrument Telemetry	Instrument to Spacecraft
0x20	Instrument Science Data	Instrument to Spacecraft

- Six types of CII packets
- Each packet type is assigned a type code and data path (either instrument to spacecraft or vice-versa).



3.2.1 CII Packet Format



CII SpaceWire Packet						
SpW Logical Address	Cargo					Exp
	Protocol ID (0x02)	Reserved (0x00)	Type Code	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	15–251 bytes (TBR)	1 byte	4 bits

Specification Legend

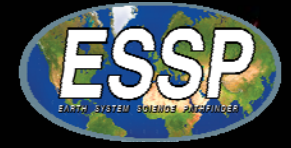
- SpaceWire (ECSS-E-ST-50-12C)
- SpaceWire Protocol Identification (ECSS-E-ST-50-51C)
- SpaceWire – CCSDS Packet Transfer Protocol (ECSS-E-ST-50-53C)
- GOES-R Reliable Data Delivery Protocol (417-R-RPT-0050; uses CRC only)

- CII builds upon several SpaceWire and packet data standards.
- 256 byte packet size by Northrup Grumman / JWST recommendation.
- CRC provides reliable data transport for instruments that may require it; adds verification to commanding.

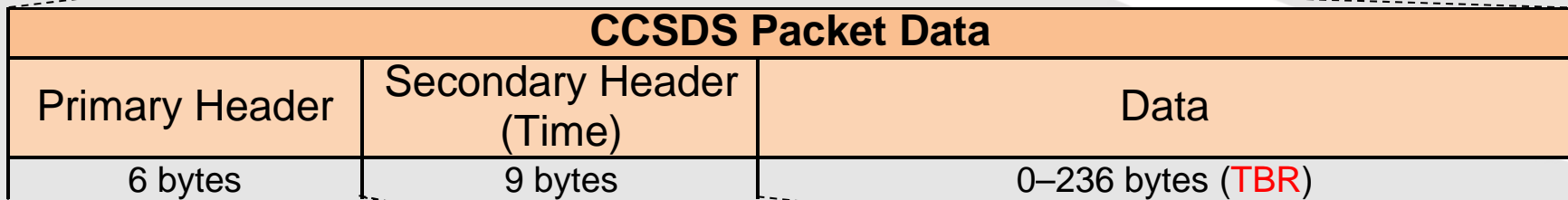
* GOES-R CRC is the standard CRC8, ATM (HEC): $x^8 + x^2 + x + 1$, with an initial value of all bits set to 1.



3.2.1 CII Packet Format (CCSDS)



CII SpaceWire Command Packet						
SpW Logical Address	Cargo					ExP
	Protocol ID (0x02)	Reserved (0x00)	Type (0x04)	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	18-251 bytes (TBR)	1 byte	4 bits



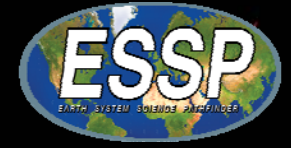
CCSDS Primary Header						
Packet Version Number	Packet Identification			Packet Sequence Control		Packet Length
	Type	Secondary Header Flag	ApID	Sequence Flags	Sequence Count	
3 bits	1 bit	1 bit	11 bits	2 bits	14 bits	16 bits
	2 bytes			2 bytes		2 bytes

CCSDS Secondary Header							
CCSDS Unsegmented Time Code (CUC) Field							
P-Field				T-Field			
Default		Extended		Coarse Time		Fine Time	
1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte

CII utilizes standardized CCSDS header format for information common to all packetized telemetry (e.g. type, length, counters, and time).



3.2.1 CII CCSDS Headers (1/2)



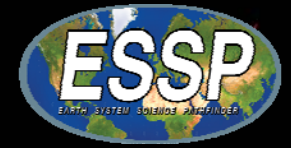
CCSDS Packet Data		
Primary Header	Secondary Header (Time)	Data
6 bytes	9 bytes	0-236 bytes (TBR)

CCSDS Primary Header						
Packet Version Number	Packet Identification			Packet Sequence Control		Packet Length
	Type	Secondary Header Flag	ApID	Sequence Flags	Sequence Count	
3 bits	1 bit	1 bit	11 bits	2 bits	14 bits	16 bits
2 bytes				2 bytes		2 bytes

Field	Length (bits)	Value	Comments
Packet Version Number	3	0b001	CII Packet Version 1
Packet Type	1	0b	CII SpaceWire-CCSDS packet
Secondary Header Flag	1	0b1	Indicates the CII-CCSDS secondary header is present
Application Process Identifier	11	0-2048	Reserved for instrument use
Sequence Flags	2	0b11	Indicates packet is unsegmented
Sequence Count	14	0-16383	Specifies the packet sequence count. The packet count begins at zero and resumes at zero after 16384 packets have been sent.
Packet Length	16	0-236	Specifies the length of the packet data field in bytes.



3.2.1 CII CCSDS Headers (2/2)



CCSDS Packet Data		
Primary Header	Secondary Header (Time)	Data
6 bytes	9 bytes	0-236 bytes (TBR)

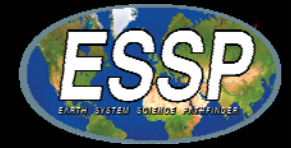
CCSDS Secondary Header								
CCSDS Unsegmented Time Code (CUC) Field								
P-Field			T-Field					
Default	Extended	Coarse Time			Fine Time			
1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte

- Contains elapsed time (ET) in coarse (seconds) and fine (sub-second) units since the default CCSDS epoch of January 1, 1958.
- Example:
 - From 1/1/58 to 2/7/11 is 1,675,728,000s → Coarse: 0x63 0xE1 0x94 0x80
 - 125ms clock tick is $2^{24} \div 8 = 2,097,152$ sub-s → Fine: 0x02 0x00 0x00
- SpaceWire 6-bit time code embedded in the CUC Extended time P-Field¹

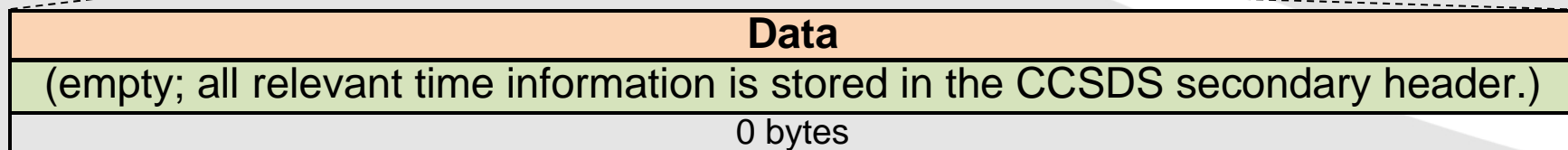
¹Defined in the SpaceWire – CCSDS Unsegmented Code Transfer Protocol (proposed)



3.2.2 Time Message



CII SpaceWire Time Packet						
SpW Logical Address	Cargo					ExP
	Protocol ID (0x02)	Reserved (0x00)	Type (0x01)	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	15 bytes	1 byte	4 bits

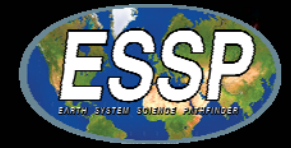


- Upon receipt of a time message, the instrument *should* update its internal clock to match (within the resolution of the instrument clock) the current spacecraft time. For details, see [1].
- The instrument *should* receive time messages at 30 second (**TBR**) intervals.

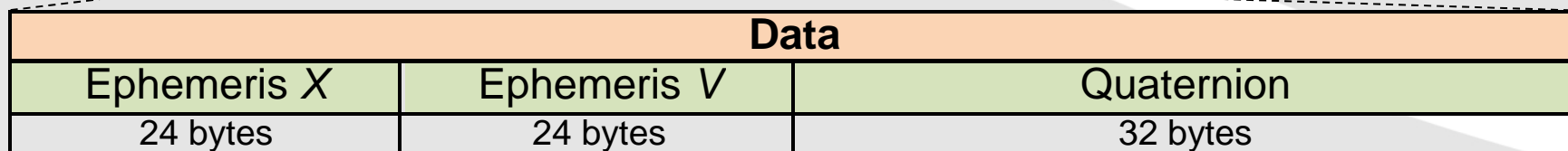
[1] SpaceWire – CCSDS Unsegmented Code Transfer Protocol (proposed)



3.2.3 Ephemeris Message



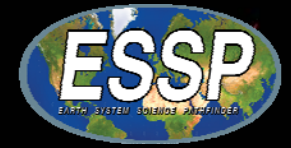
CII SpaceWire Ephemeris Packet						
SpW Logical Address	Cargo					ExP
	Protocol ID (0x02)	Reserved (0x00)	Type (0x02)	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	143 bytes	1 byte	4 bits



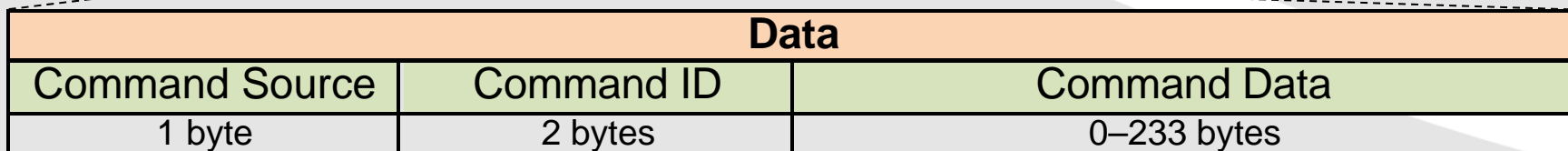
- The instrument *should* receive ephemeris messages at (TBR) intervals.
- 80 bytes of data:
 - 4-element, double-precision, non-dimensional quaternion.
 - 3-element, double-precision, position vector (X).
 - 3-element, double-precision, inertial velocity vector (V).
- Follows STP–SIV ephemeris message format.



3.2.4 Instrument Command



CII SpaceWire Command Packet						
SpW Logical Address	Cargo					ExP
	Protocol ID (0x02)	Reserved (0x00)	Type (0x04)	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	18-251 bytes (TBR)	1 byte	4 bits

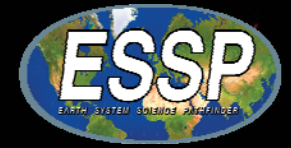


Command Source	Command Origination Point
0x01	Spacecraft
0x02	Ground

- Most commands are opaque (i.e. pass-through from the ground) to the spacecraft except SAFE and PING.
- The instrument *should* enter safe mode when it receives a command from the spacecraft (Command Source=0x01) or ground (Command Source=0x02) with a Command Identifier of 23294 (0x5AFE) (TBR).



3.2.5 Command Acknowledgement



CII SpaceWire Command Acknowledgement Packet						
SpW Logical Address	Cargo					ExP
	Protocol ID (0x02)	Reserved (0x00)	Type (0x08)	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	24 bytes	1 byte	4 bits

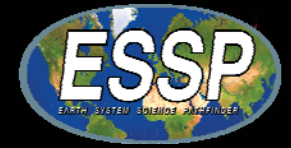
Data				
Instrument Mode	Command Source	Command ID	Command Sequence Count	Command Status
2 bytes	1 byte	2 bytes	2 bytes	2 bytes

Command Status	Description
0x0000	Command Received and Processed
0x0001	Duplicate Command Received (TBR)
0x0002	Command Packet CRC Error (TBR)
0x00FF–0xFFFF	Instrument Specific Error Codes

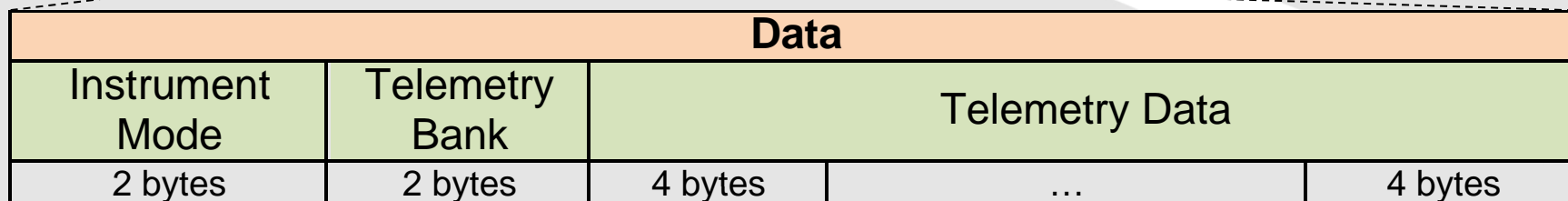
- Instrument Mode field:
 - First two bits denote the instrument major mode: INITIALIZATION (0b00), OPERATION (0b01), or SAFE (0b10)
 - Remaining bits may be used at the instrument’s discretion
- Command Source, Command ID, and CCSDS Primary Header Sequence Count fields are **echoed** from the command packet being acknowledged.



3.2.6 Instrument Telemetry



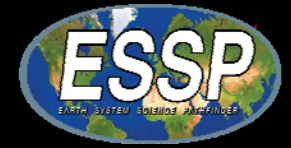
CII SpaceWire Telemetry Packet						
SpW Logical Address	Cargo					ExP
	Protocol ID (0x02)	Reserved (0x00)	Type (0x10)	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	251 bytes (TBR)	1 byte	4 bits



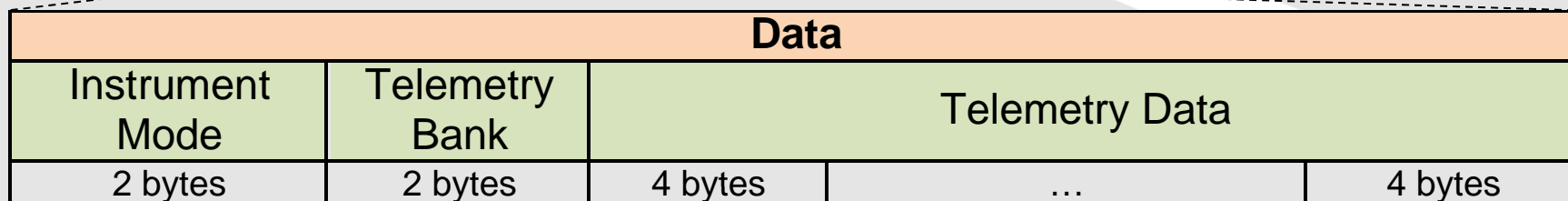
- Instrument Mode field:
 - First two bits denote the instrument major mode: INITIALIZATION (0b00), OPERATION (0b01), or SAFE (0b10)
 - Remaining bits may be used at the instrument's discretion
- 58 (TBR) telemetry values per packet / telemetry bank.
- To facilitate spacecraft monitoring, each instrument telemetry value *should* be encoded as either:
 - a standard two's complement **32-bit signed integer**,
 - a **32-bit unsigned integer**, or
 - a **IEEE-754 floating-point** values.



3.2.6 Instrument Telemetry



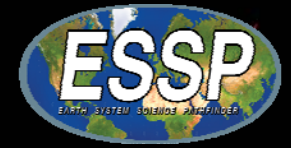
CII SpaceWire Telemetry Packet						
SpW Logical Address	Cargo					ExP
	Protocol ID (0x02)	Reserved (0x00)	Type (0x10)	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	251 bytes (TBR)	1 byte	4 bits



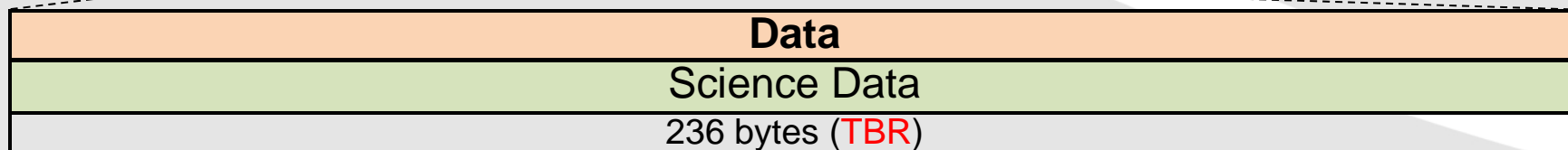
- Instrument Mode field:
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- To facilitate **spacecraft monitoring**, each instrument telemetry value *should* be encoded as either:
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3.2.7 Instrument Science Data



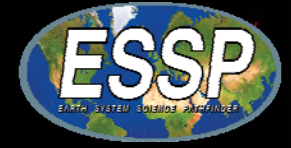
CII SpaceWire Science Data Packet						
SpW Logical Address	Cargo					ExP
	Protocol ID (0x02)	Reserved (0x00)	Type (0x20)	CCSDS Packet Data	CRC	
1 byte	1 byte	1 byte	1 byte	251 bytes (TBR)	1 byte	4 bits



- All science data is opaque to the spacecraft.
- The instrument *should* be responsible for its own:
 - science data compression,
 - onboard storage, and
 - playback
- Data playback *should* be coordinated with the spacecraft operations team.



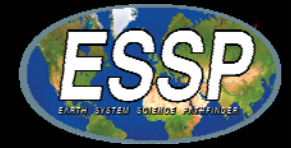
Open Items



- **Protocol Overhead**
 - SpaceWire's 8 to 10 bit encoding adds a base **20%** protocol overhead
 - **JWST** instruments NIRCam, NIRSpec, MIRI, FGS each have a **23%** total (SpaceWire plus protocol) overhead
 - CII protocol has **26%** overhead (primarily due to time in each packet)
 - For science data, JWST omits its custom SpaceWire–CCSDS protocol, and thus has only **half** the protocol-only overhead as the proposed CII protocol.
 - For comparison, on a **200 Mbps** link, JWST can achieve a maximum of **154 Mbps** of science data while CII can achieve **148 Mbps**.
- **Is it feasible to standardize ephemeris / pointing frames?**
- **SpaceWire time code / spacecraft primary 1 PPS signal synchronization**
- **Finalize clock rates, data rates, and message frequency**



Data Testbed Capabilities



In order to perform hardware and software validation of the CII data requirements, the CII Data Testbed will provide:

- **Instrument Simulation**

- C&DH
- Canned science and telemetry data from a variety of (JPL) instruments at low, medium, and high representative data rates

- **Spacecraft Simulation**

- C&DH
- Canned time and ephemeris data

- **Data Monitoring**

- via instrument and spacecraft simulator logging and commercial SpaceWire test equipment

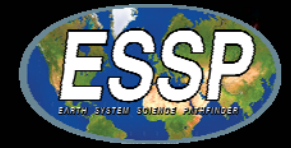
- **Error Injection**

- via commercial SpaceWire diagnostic equipment

- **Storage and querying of data generated during a test**



Abbreviations and Acronyms



APID	Application Process Identifier	
CCSDS	Consultative Committee for Space Data Systems	
CII	Common Instrument Interface	
CUC	CCSDS Unsegmented (Time) Code	
CRC	Cyclic Redundancy Check	
ECSS	European Cooperation for Space Standardization	
EEP	Error End of Packet	
EOP	End Of Packet	
ExP	Either EEP or EOP	
EV-I	Earth Venture Instrument	
FGS	Fine Guidance Sensor	(JWST instrument)
JWST	James Webb Space Telescope	
MIRI	Mid-Infrared Instrument	(JWST instrument)
NIRCam	Near-Infrared Camera	(JWST instrument)
NIRSpec	Near-Infrared Spectrograph	(JWST instrument)
PPS	Pulse Per Second	
SpW	SpaceWire	
TBD	To Be Determined	
TBR	To Be Resolved	