The Cubesat Laser Infrared CrosslinK mission (CLICK)

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Precision Space Systems Lab, University of Florida

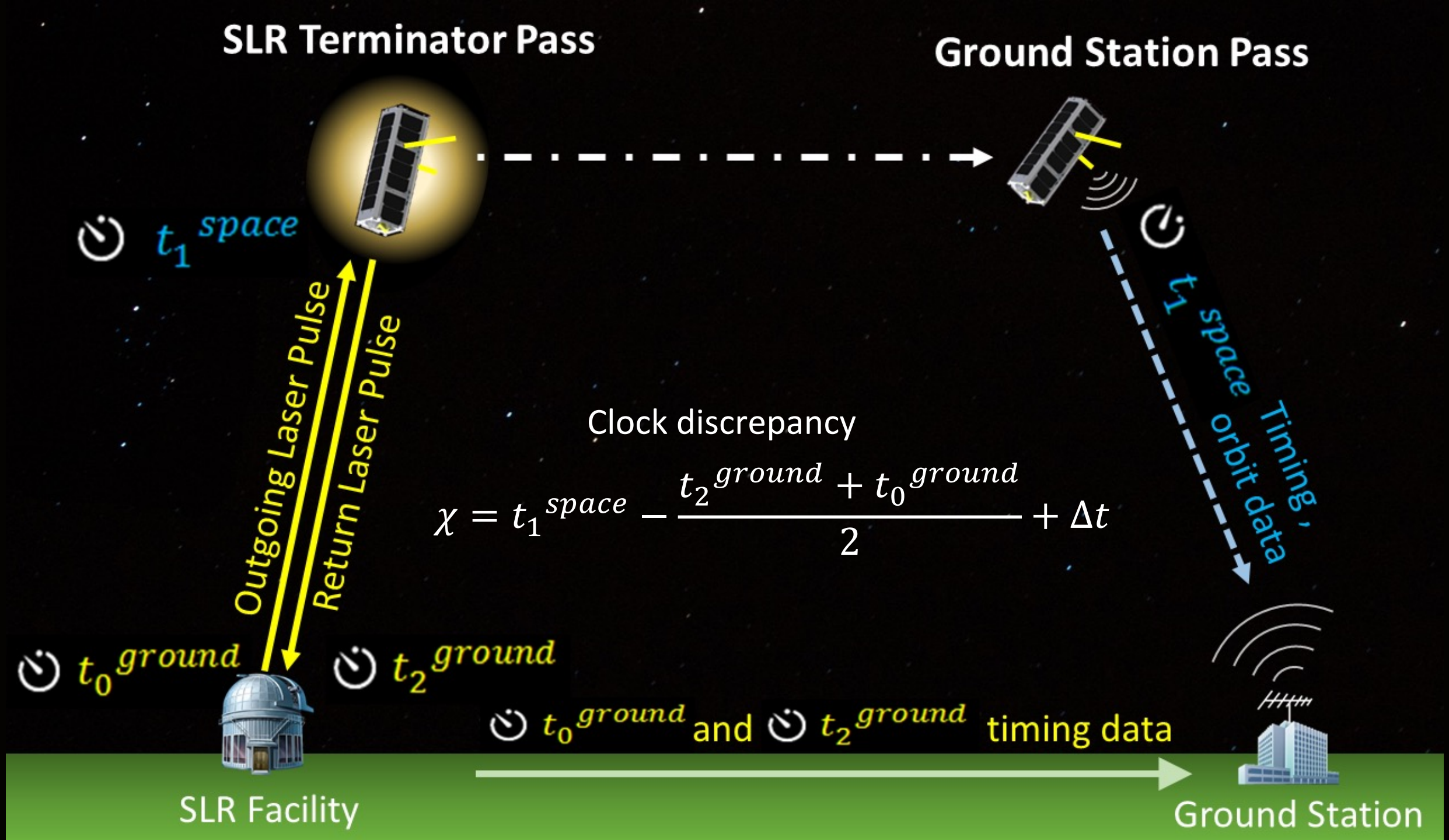
SCPNT Symposium
12th October 2022

CHOMPTT - Cubesat Handling Of Multi-system Precision Time-Transfer

University of Florida – Precision Space Systems Lab

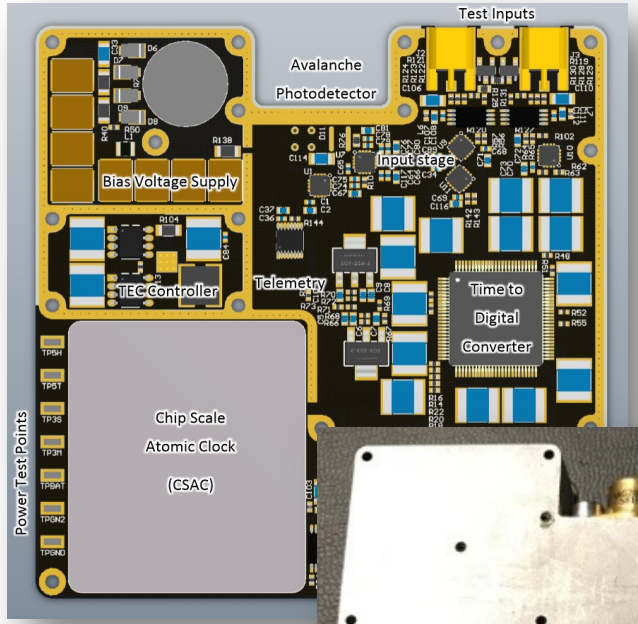
NASA - Ames Research Center

- LV Integration: April 2018
- Launch: 18 Dec 2018
- NASA ELaNa XIX
- Rocket Lab's 4th Launch
  - "This One's for Pickering"
  - First NASA Launch
- 500 km circle × 85 deg
- ~7 years to re-entry


SLR Terminator Pass
Ground Station Pass
$t_1{}^{space}$
Outgoing Laser Pulse
Return Laser Pulse
$t_1{}^{space}$
Timing, orbit data
Clock discrepancy
$\chi = t_1{}^{space} - \frac{t_2{}^{ground} + t_0{}^{ground}}{2} + \Delta t$
$t_0{}^{ground}$
$t_2{}^{ground}$
$t_0{}^{ground}$ and $t_2{}^{ground}$ timing data
SLR Facility
Ground Station

Optical Precision Time-transfer Instrument (OPTI) - v3.1 (flight)

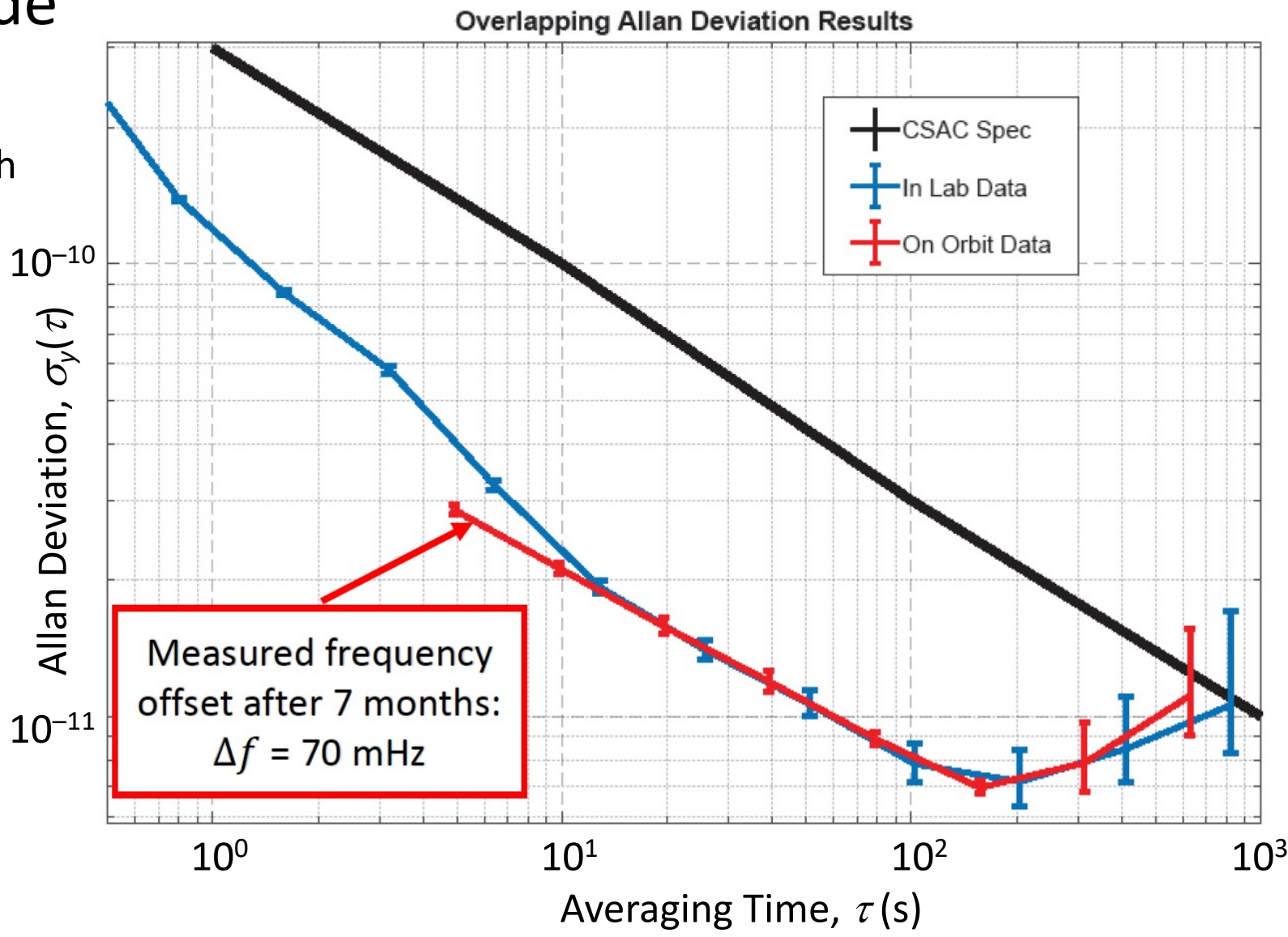
- Primary CHOMPTT mission payload element
- Custom PSSL design:
  - APD-based Photoreceiver
    - Tunable reverse bias for gain control, adjustable threshold
    - Thermo-electric cooler control → stable breakdown voltage
  - Precision oscillator (Chip Scale Atomic Clock)
    - Allan Dev. 3.3x10–12 @ 90 min → 20 ns (6 m)
  - Time-to-Digital Converter: ACAM TDC-GPX
    - 10 ps (3 mm) time-stamping (fine time)
  - Microcontroller: TI MSP-430
    - CSAC clock counter @ 10 MHz (course time)
- Two identical A/B OPTI channels flown



Long Term Performance

Clock Comparison Mode

- Both CSACs disciplined to Rb standard ~1 year before launch
- Allan Deviation calculated from χ time-series using IEEE, Stable32
- Timing error calculated explicitly at $\tau = 6{,}000$ s (1 orbit)
  - $\sigma_y(6{,}000) \times 6{,}000 = 19 \pm 12$ ns
  - Level 1 requirement: Error <20 ns @ tau = 1 orbit ✓
  - Excluded first orbit data



CLICK - The CubeSat Laser Infrared Crosslink Mission

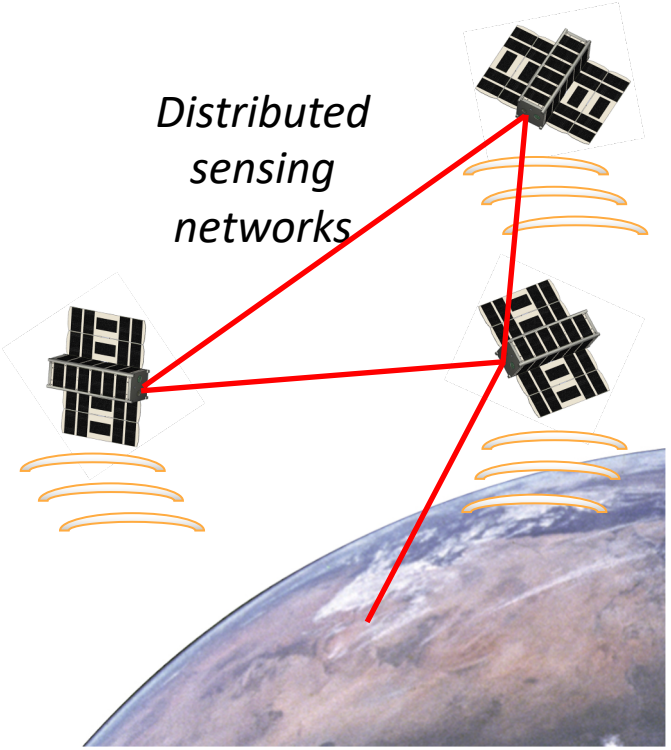
Massachusetts Institute of Technology – Space Telecommunications, Astronomy and Radiation Laboratory Lab

University of Florida – Precision Space Systems Lab

NASA - Ames Research Center

CubeSat Laser-Comm

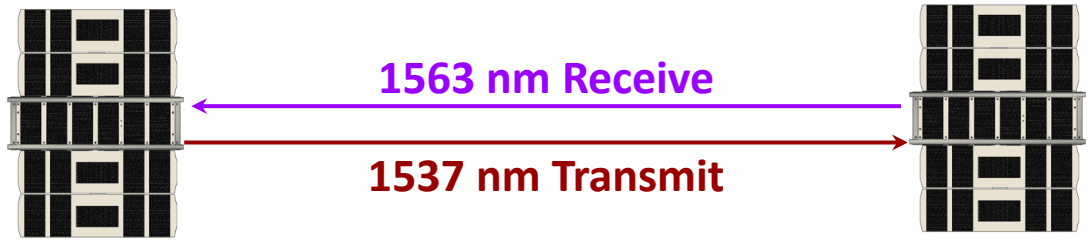
- The **CubeSat** Standard
  - A satellite made from 'units' of $10\text{x}10\text{x}10\ \text{cm}^3$ (1L)
  - Standardized launch & deployment systems
- Can enable new **distributed & coordinated sensing missions**
- There is a need for:
  - **Mbps-rate** full-duplex crosslinks
  - **Precision ranging** and timing
- **Goal**: Development of miniaturized optical transceivers based on COTS components & compatible with CubeSat SWaP constraints
- CLICK-BC's objective:
  - **20 Mbps** and **6 cm instantaneous** at **580 km** in **1.5U**
    - (<0.5 m orbit average)



Slide: O. Cierny

The CLICK-BC Mission

- Pair of **1.5 U, ~1700 g, <25 W** payloads flown on two 3U CubeSats
- **200 mW** avg. Tx, **70 µrad** divergence
- **2.5 cm** receive aperture
- **500 mW** beacon at 976 nm for PAT
- Full-duplex **PPM** crosslinks 1537/1565 nm
  - **50 Mbps**, 4-PPM, <450 km
  - **25 Mbps**, 16-PPM, <920 km
- **200 ps** timing accuracy & time transfer
- Primary success criteria:
  - >20 Mbps full-duplex @ 580 km
  - <0.5 m ranging w/o GPS @ 580 km



Slide: O. Cierny

Optical Bench Layout

Transmit
200 mW, 1537 nm
120 µrad 1/e²

Receive
1563 nm
20 mm aperture

Beacon
250 mW, 976 nm
22 mrad 1/e²

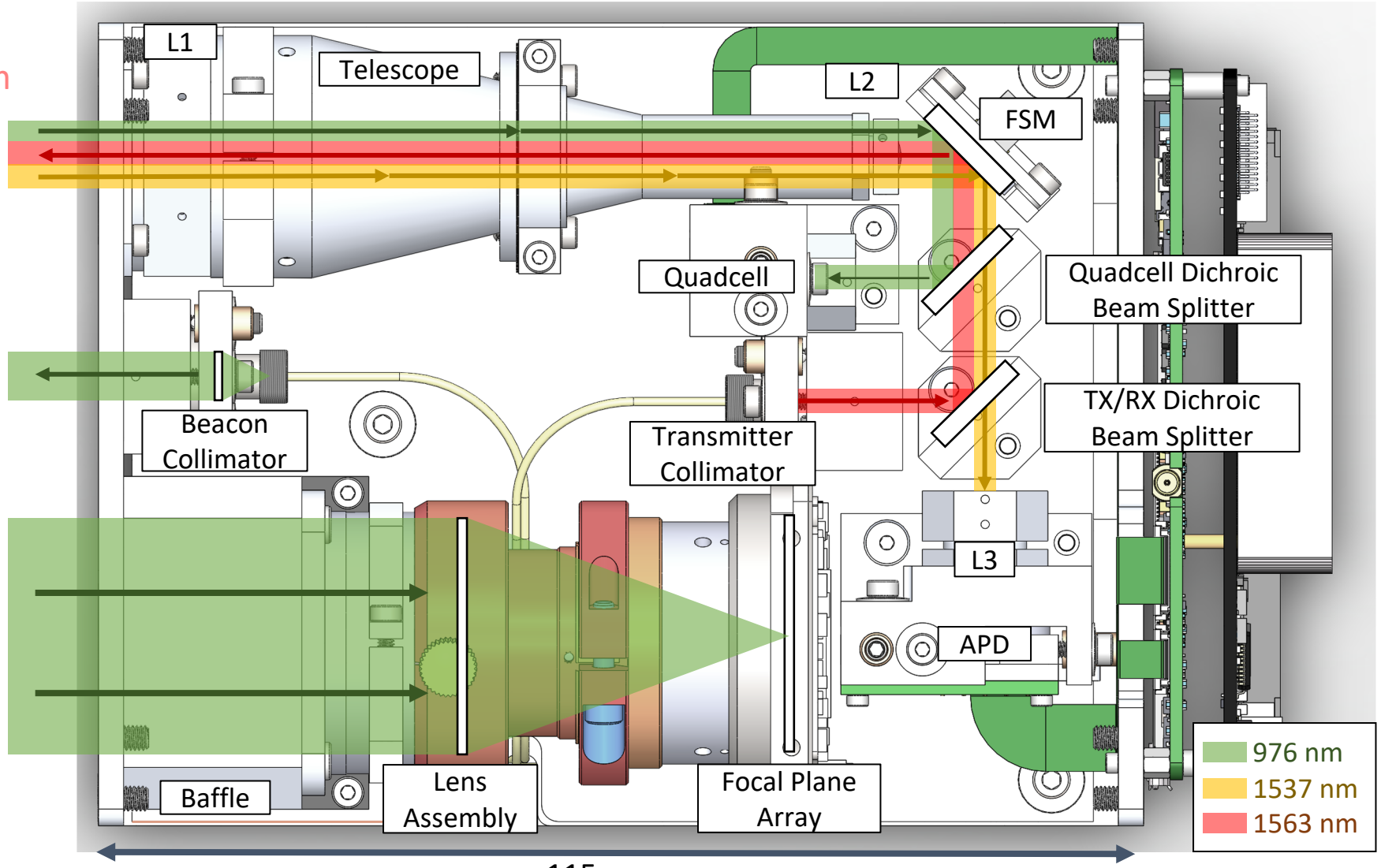
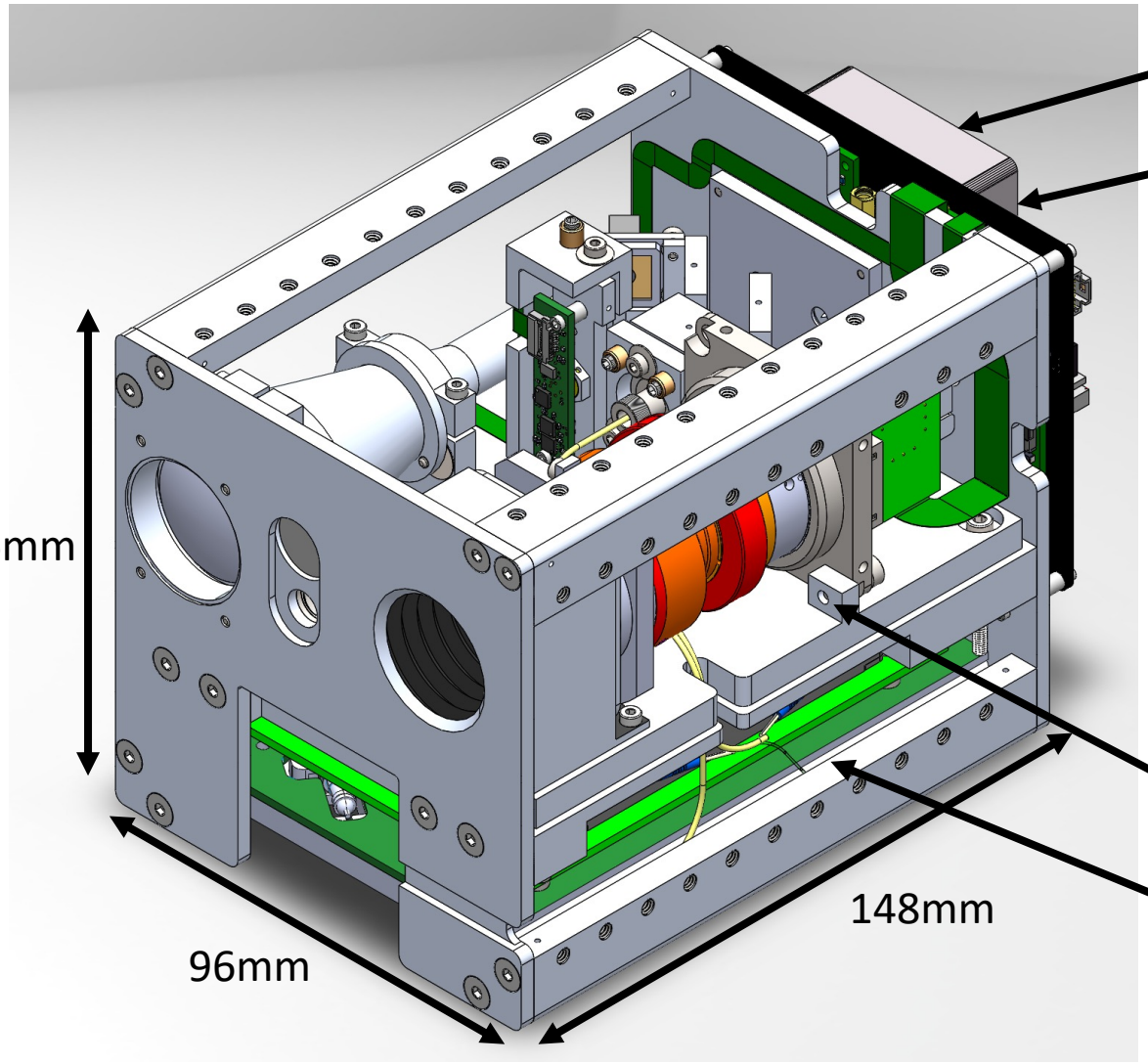
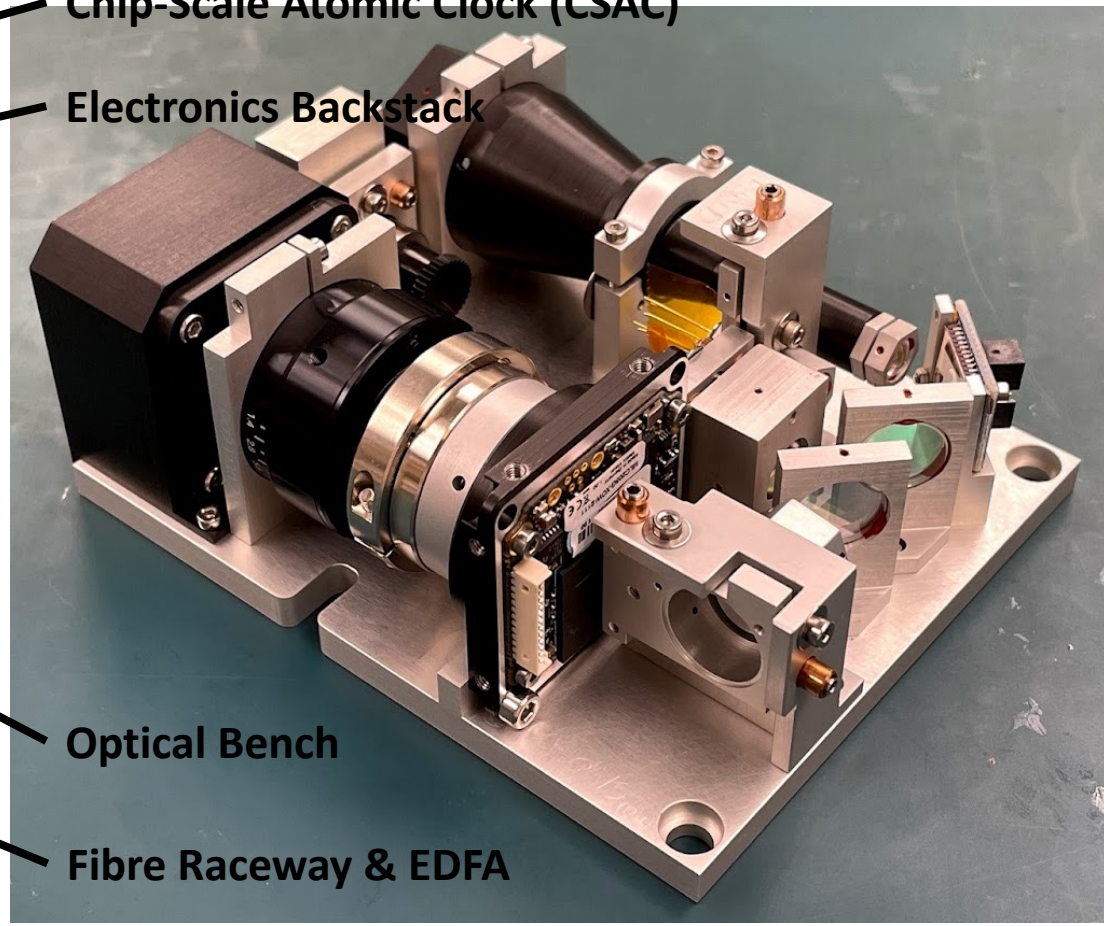


Image: H. Tomio

Payload Layout





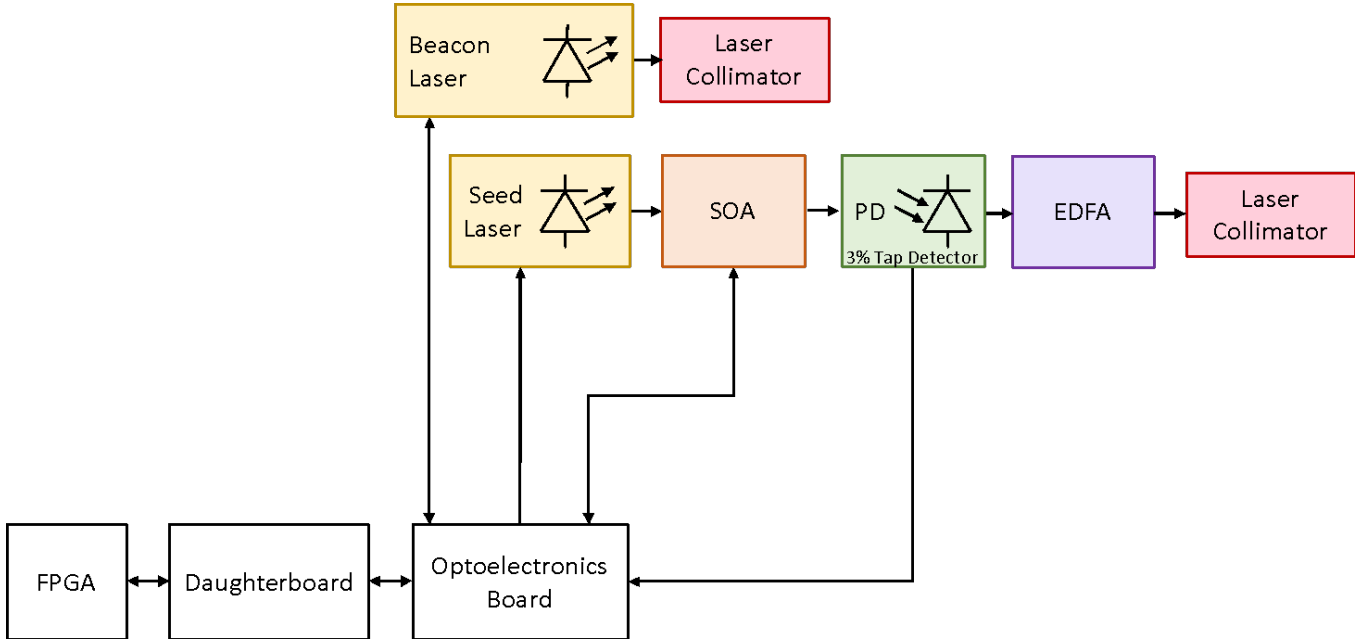
Chip-Scale Atomic Clock (CSAC)

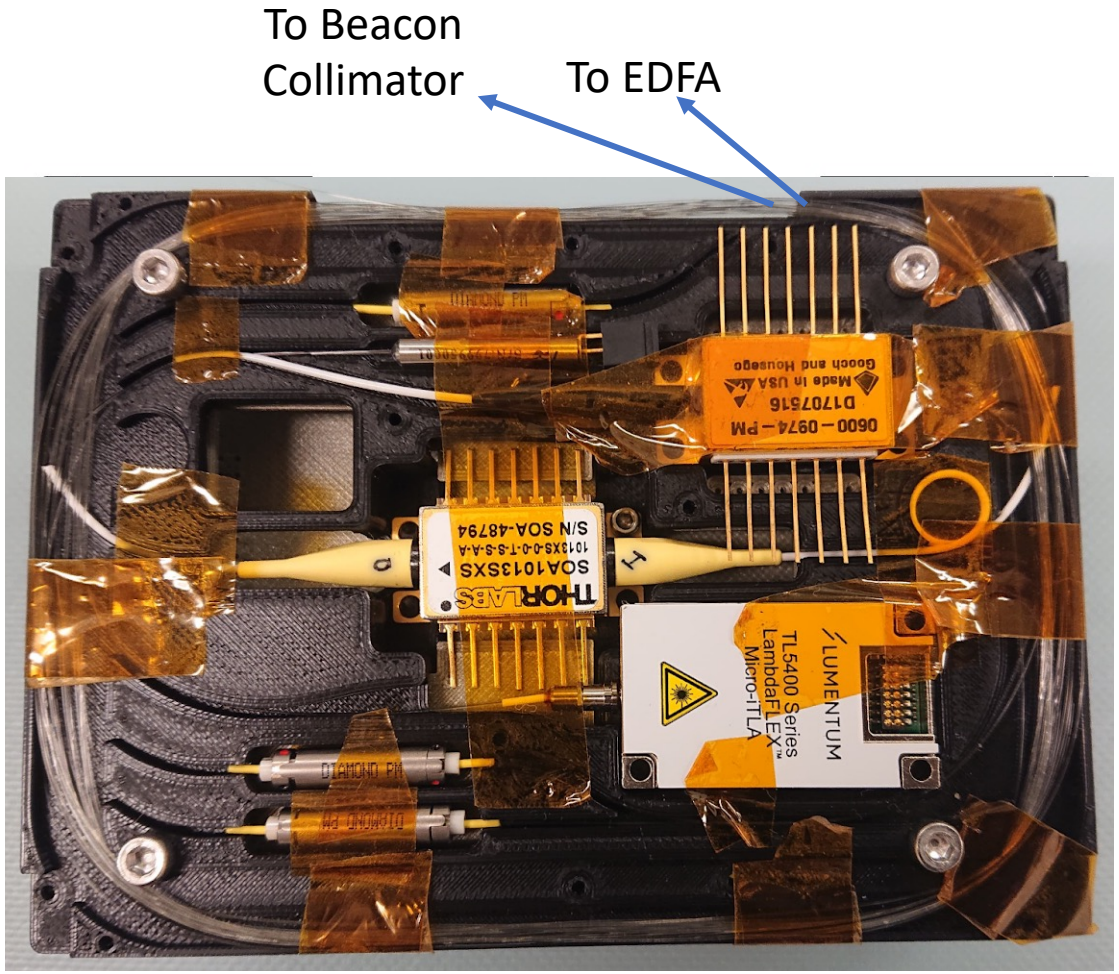
Electronics Backstack

Optical Bench

Fibre Raceway & EDFA

Fiber Raceway

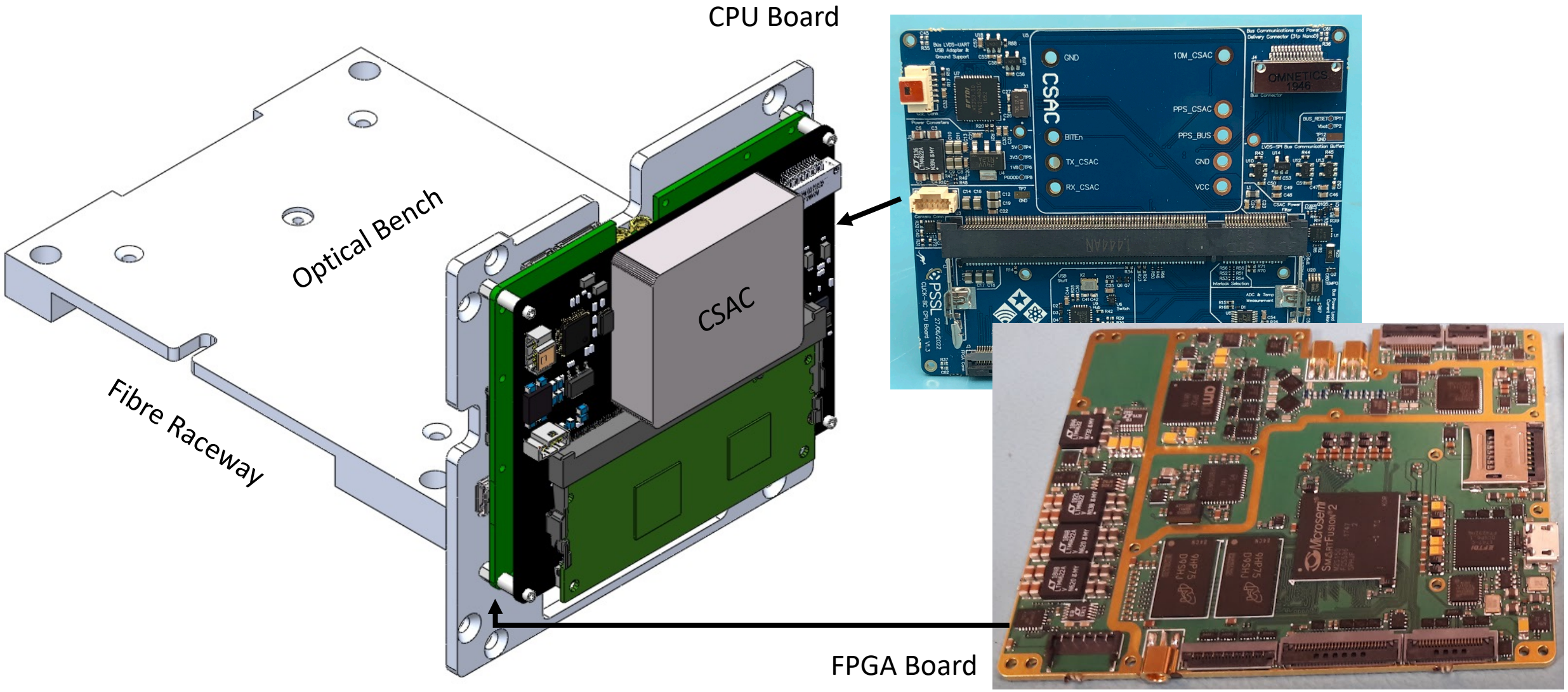




Tunable Seed Laser

Thorlabs SOA Optical Shutter

Electronics Backstack



CPU Board

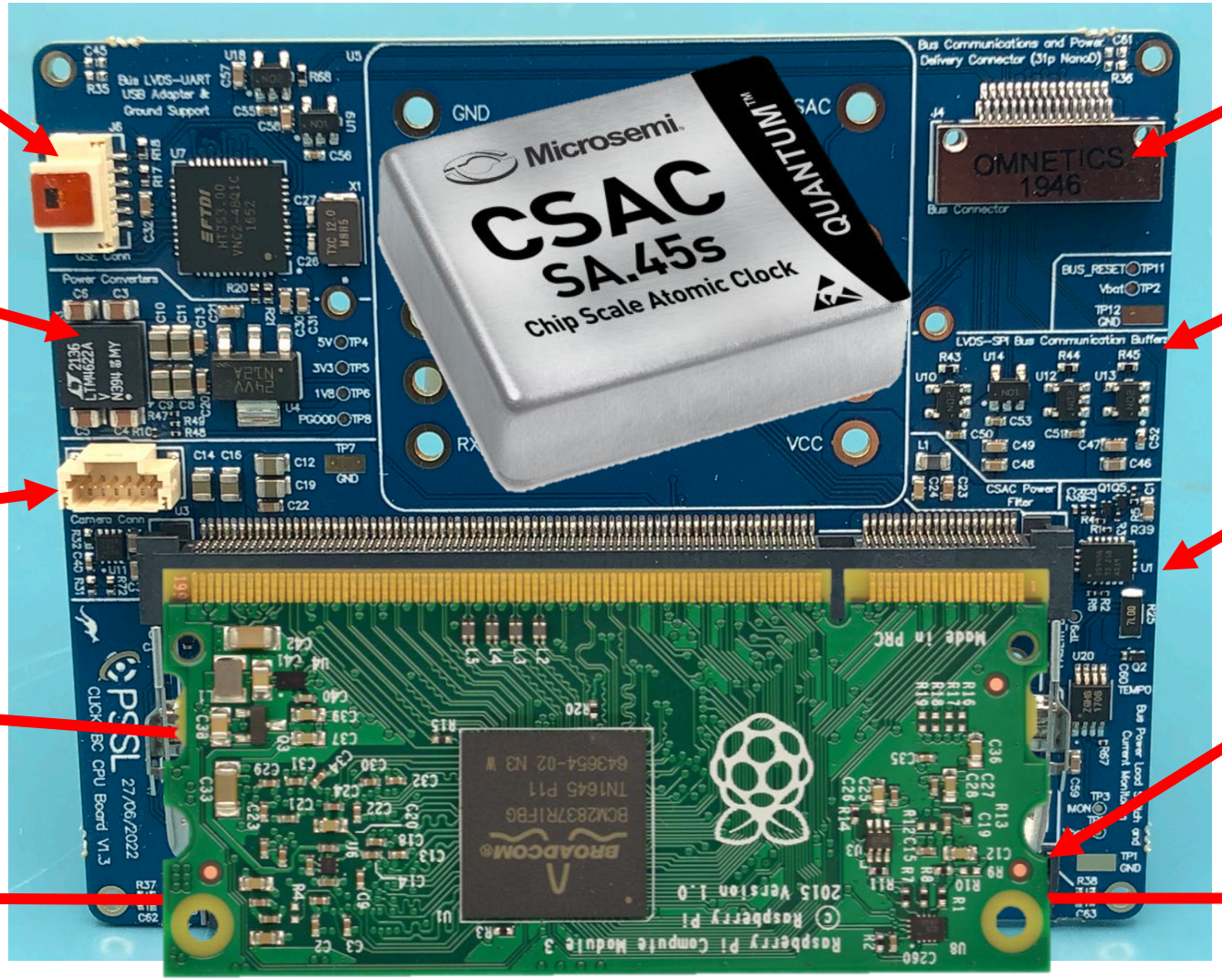
Ground Support Connector

RPi CPU Power Converters

Tracking Camera Connector

USB Hub

FPGA Board Data Connector



Spacecraft Bus Connector (Power & Data)

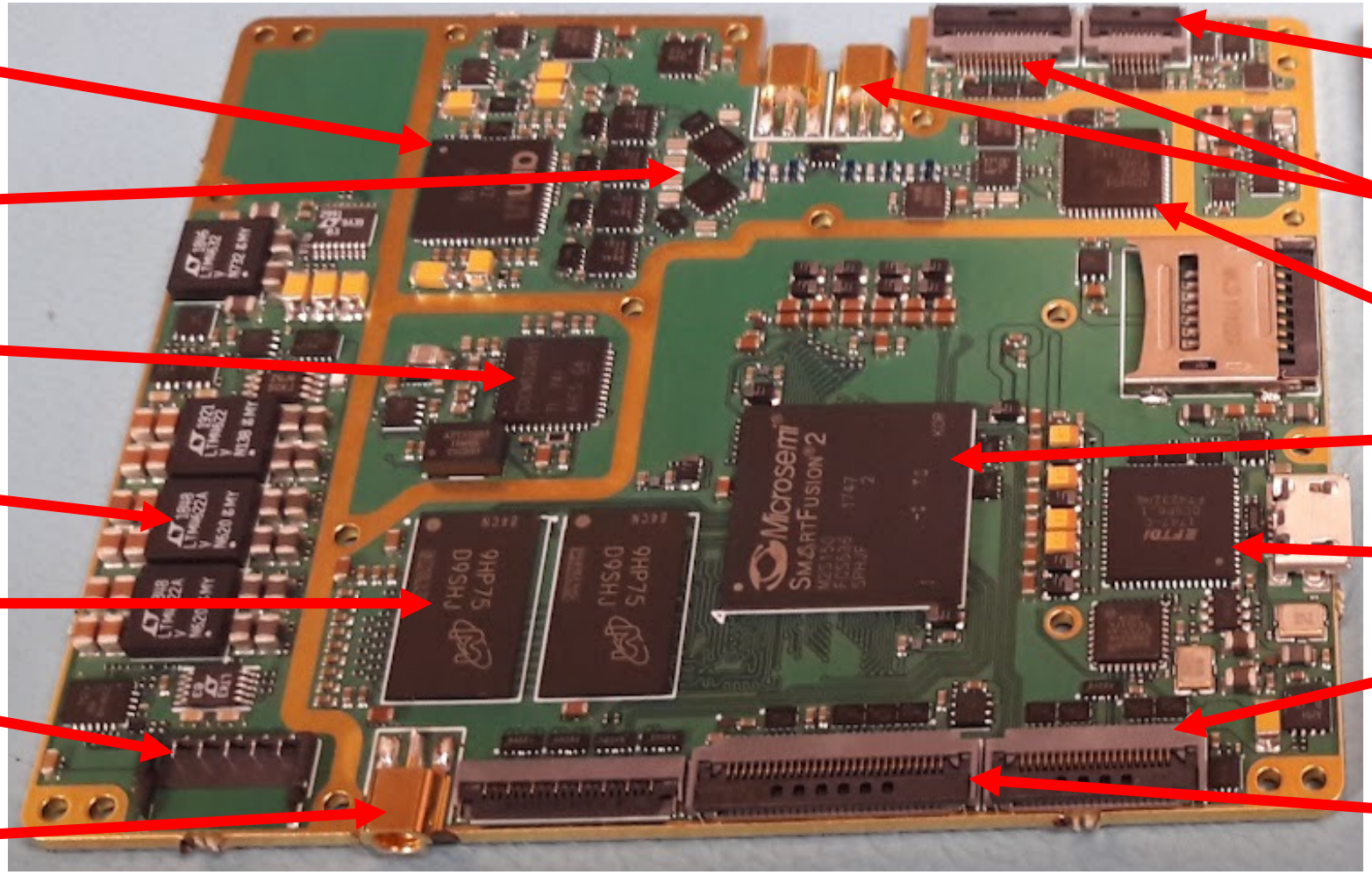
Differential SPI Buffers for Bus Data

Power Control and Monitoring

FPGA Board Power Connector

FPGA CSAC Reference Clock Connector

FPGA Board



ScioSense TDC-GPX2

Pulse Edge Detection

Clock Management

Power Conversion

DDR3 ECC DRAM

CPU Board Power Connector

Clock Connector

Quadcell Board Connector

APD Board Connectors

12b 500 MHz ADC

Microsemi M2S150TS-1

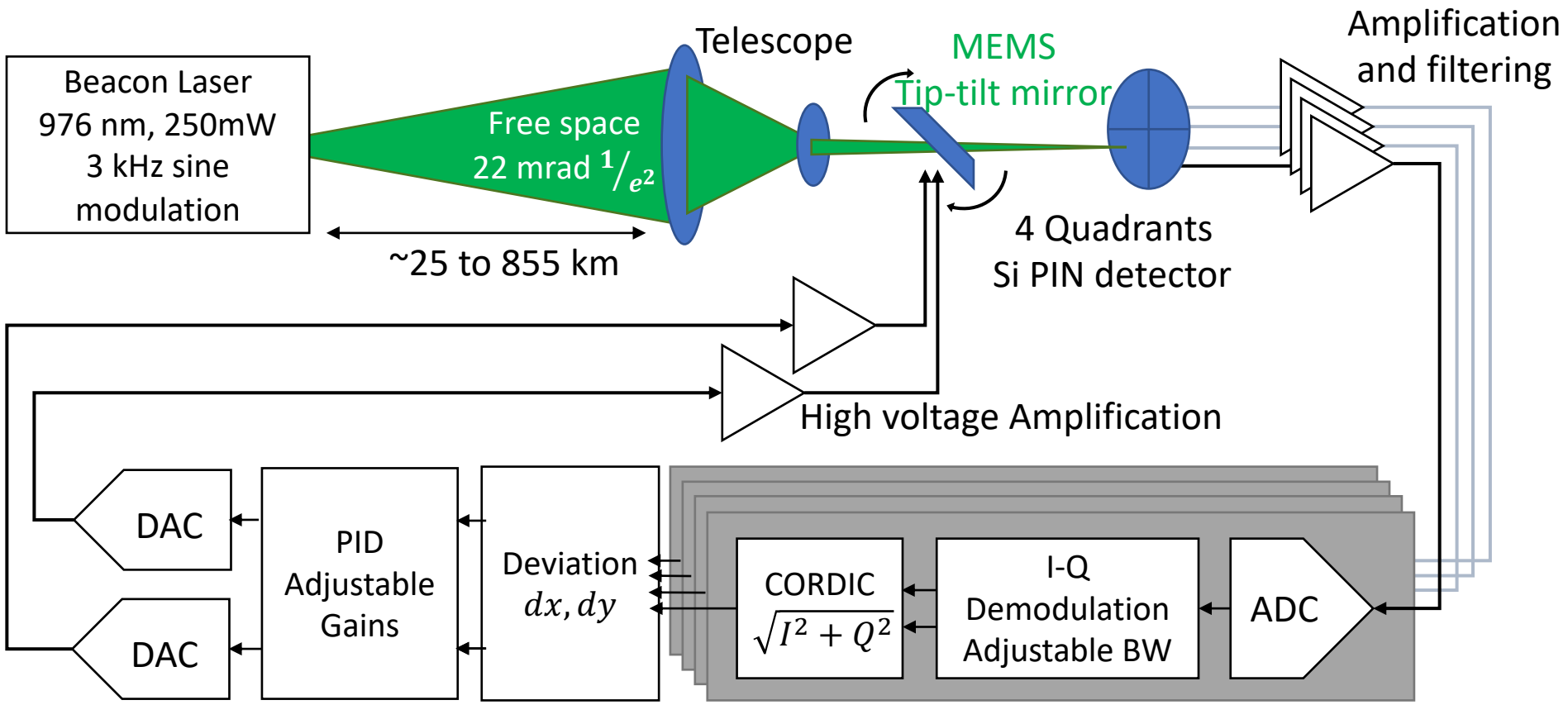
FlashPro5 Debugger

CPU Board Data Connector

Transmitter Connector

Paul Serra

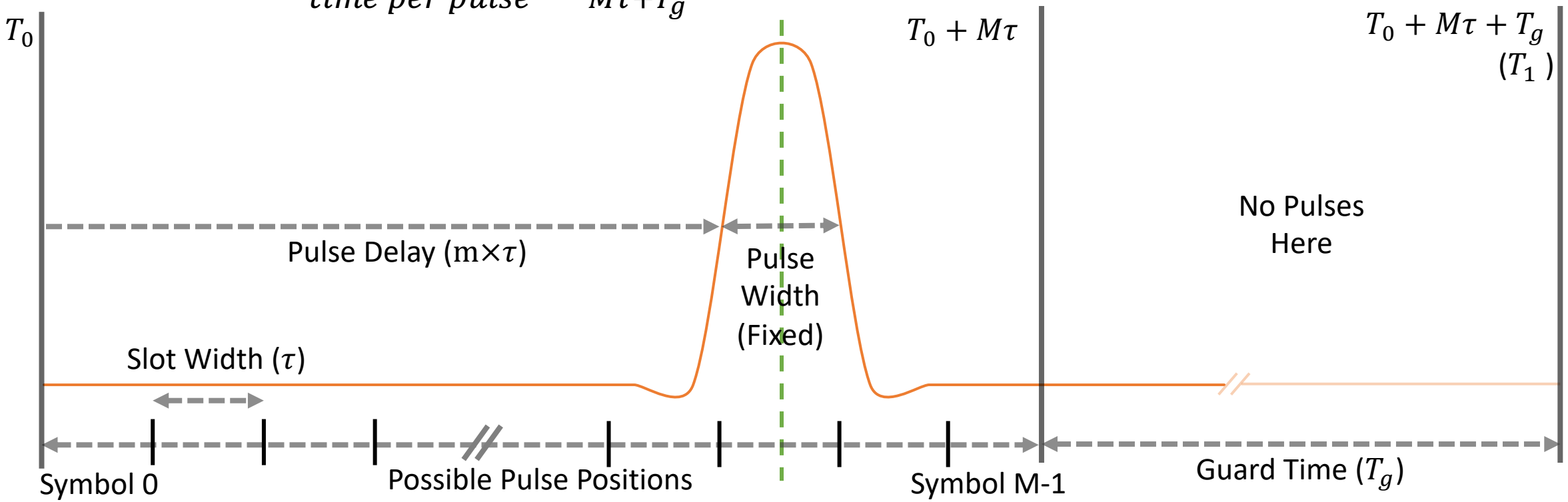
Fine Pointing And Tracking (PAT)



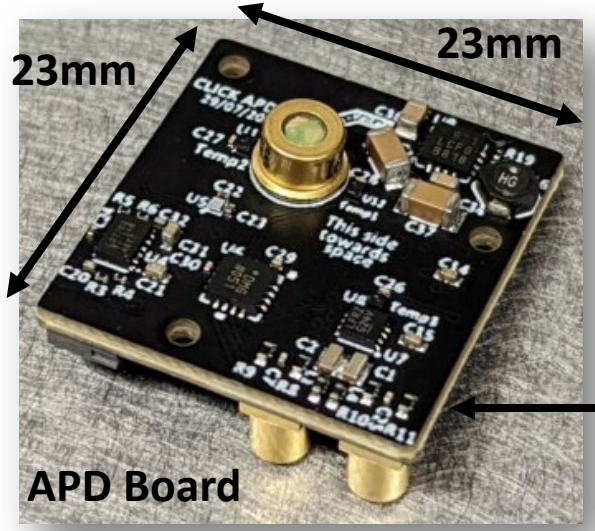
Slide: H. Tomio

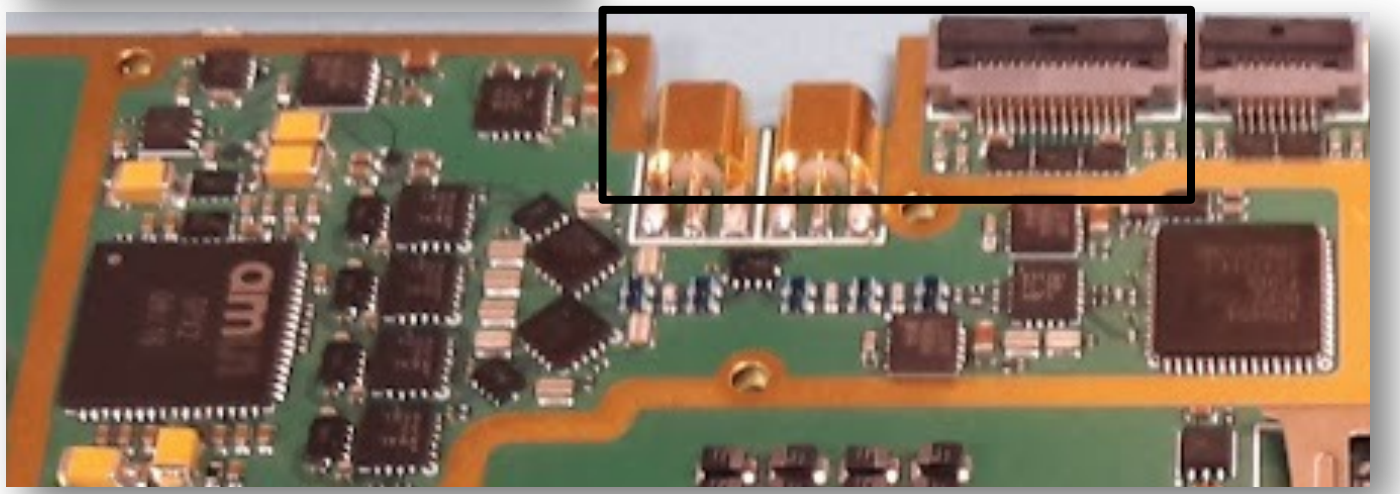
PPM Pulse Encoding

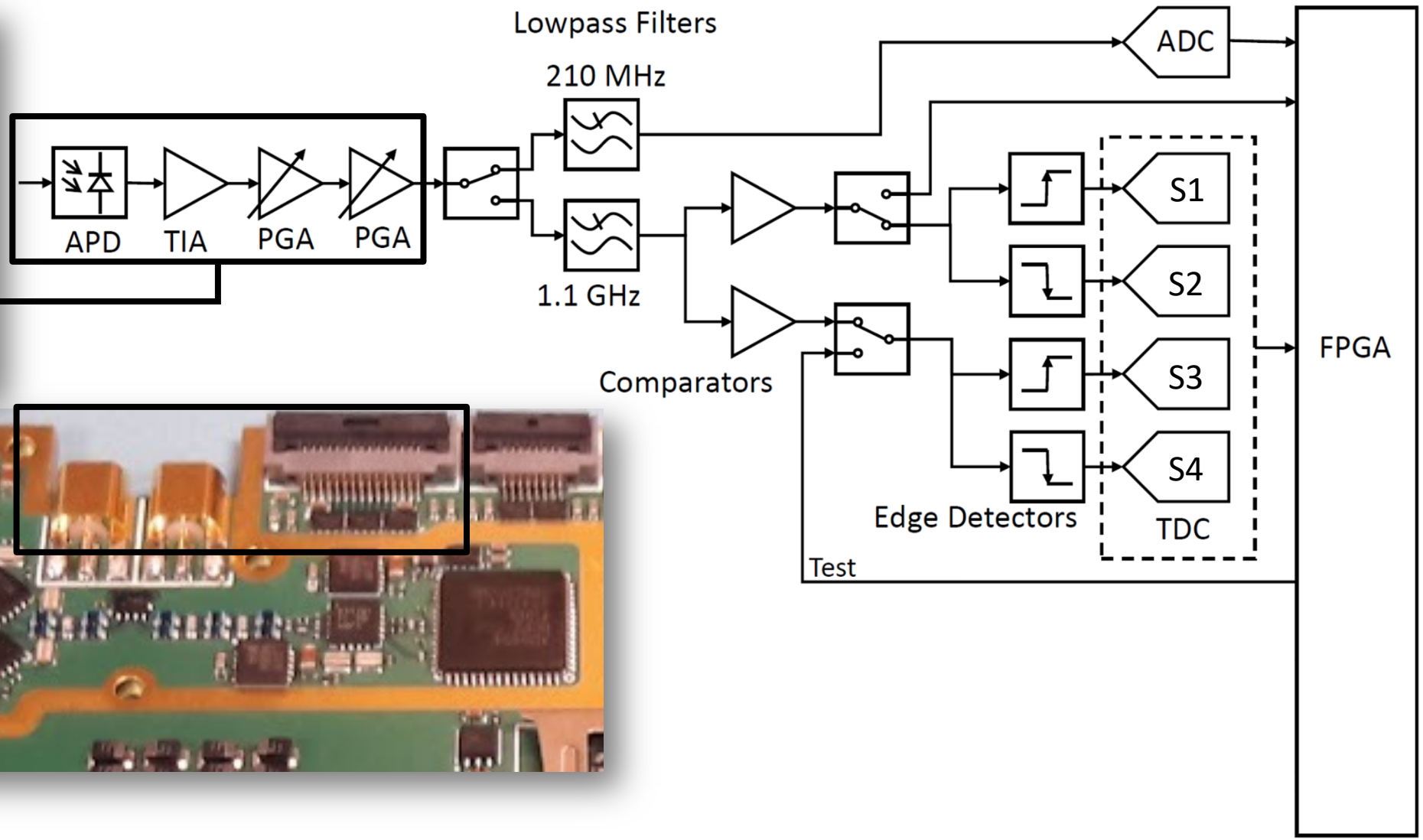
- Data encoded into symbols, which vary the pulse emission time
- Typical setting: M = 16, τ= 10 ns, T_g = 40 ns => 20 Mbps
  - $D_{PPM} = \frac{data\ per\ pulse}{time\ per\ pulse} = \frac{\log_2 M}{M\tau + T_g}$



Receiver Timestamping

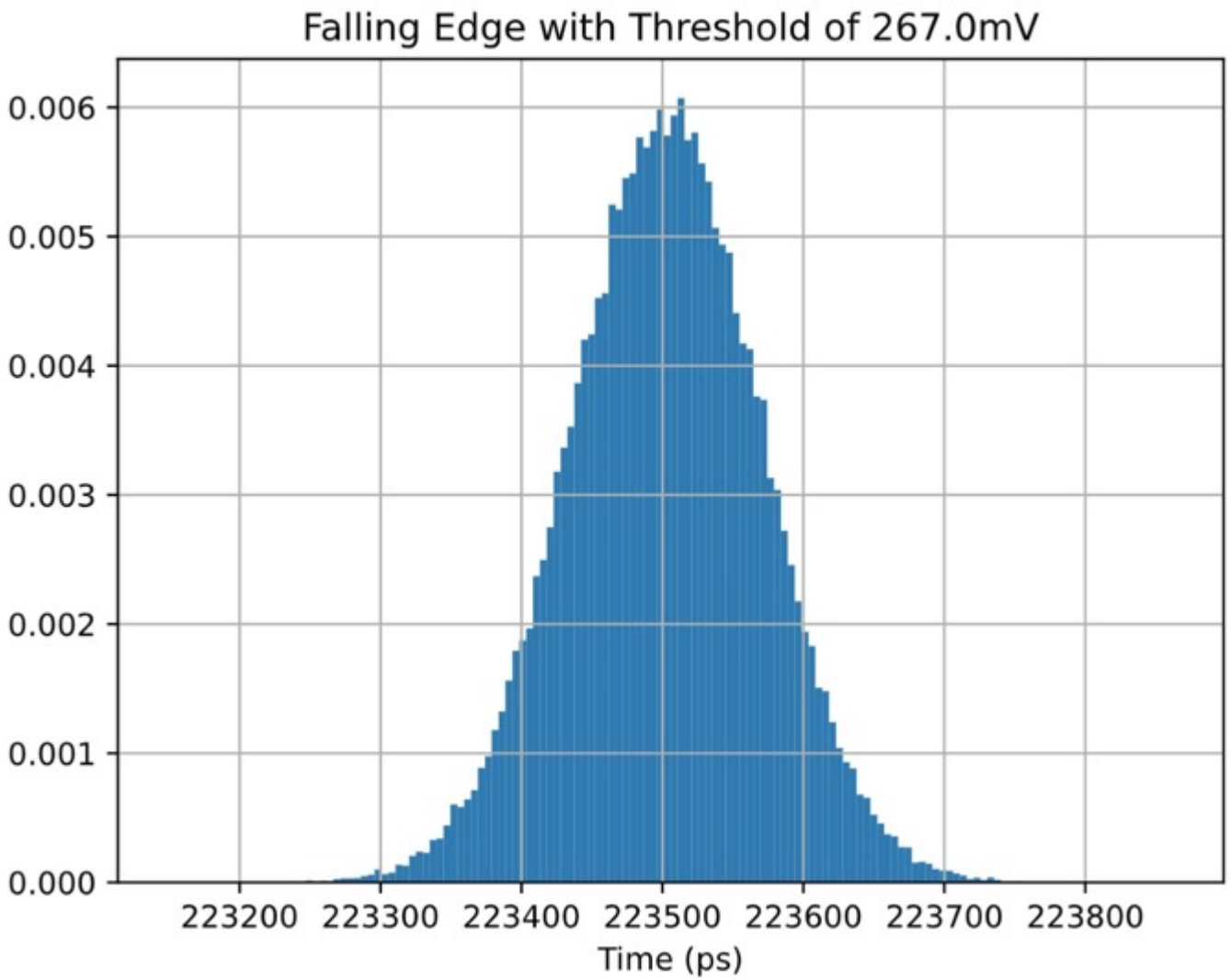






The Time to Digital Converter

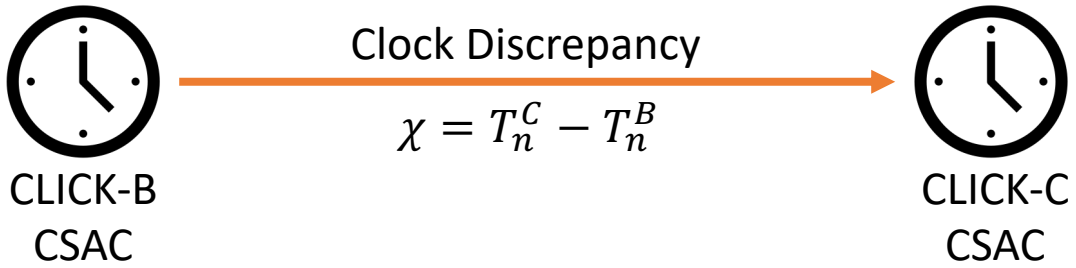
- ScioSense TDC-GPX2
  - 4-channel, 20ps RMS single-shot
  - Used at 12.5 MSps @ ~5ps resolution
- Hardware timing jitter measurement
  - Direct electrical input from modulator @ 4.5 MHz
  - Difference taken between adjacent timestamps
- Measured standard deviation of time difference: ~76 ps
  - Single-shot jitter: 54 ps

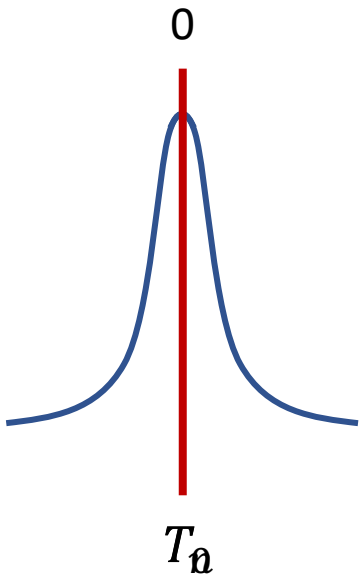


The Symbol Decoder

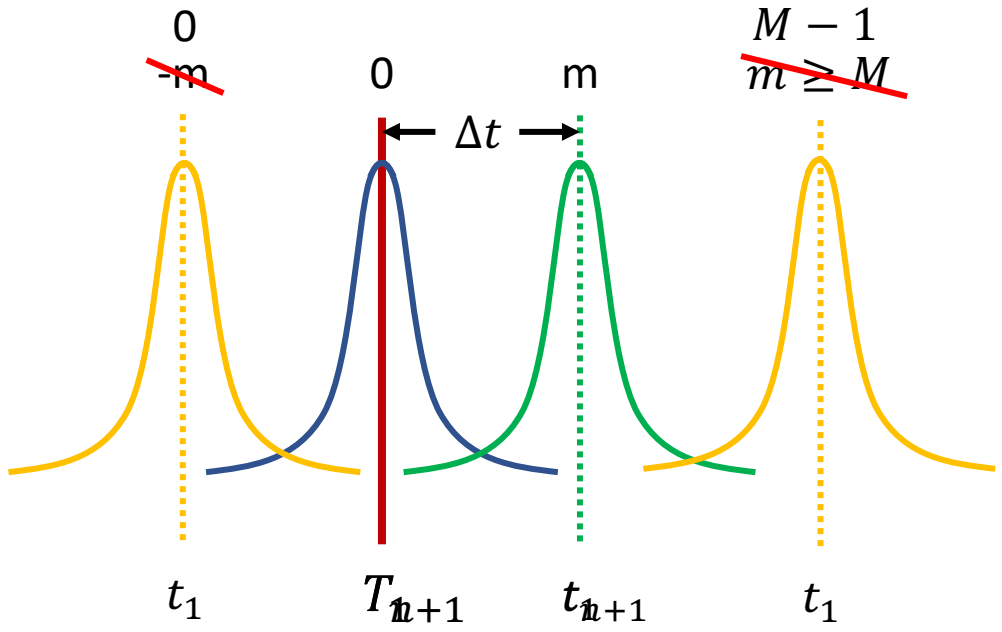
- $T_n = T_{n-1} + (M\tau + T_g)$
- $t_n = T_n + m \times \tau$
- $T_{res} \mathrel{+}= f_{error}([t_n - T_n] - [m_{bound} \times \tau])$

(Δt_{meas}) $(\Delta t_{perfect})$





$$T_{res} \approx T_{offset} + \chi$$



CLICK-BC Timeline

CLICK-BC Payload Delivery to BCT:
Early 2023

Launch to ISS on SpaceX CRS Mission:
NET Oct 2023

CLICK is supported by the NASA STMD Small Spacecraft Technology Program

PSSL

@precisionspace

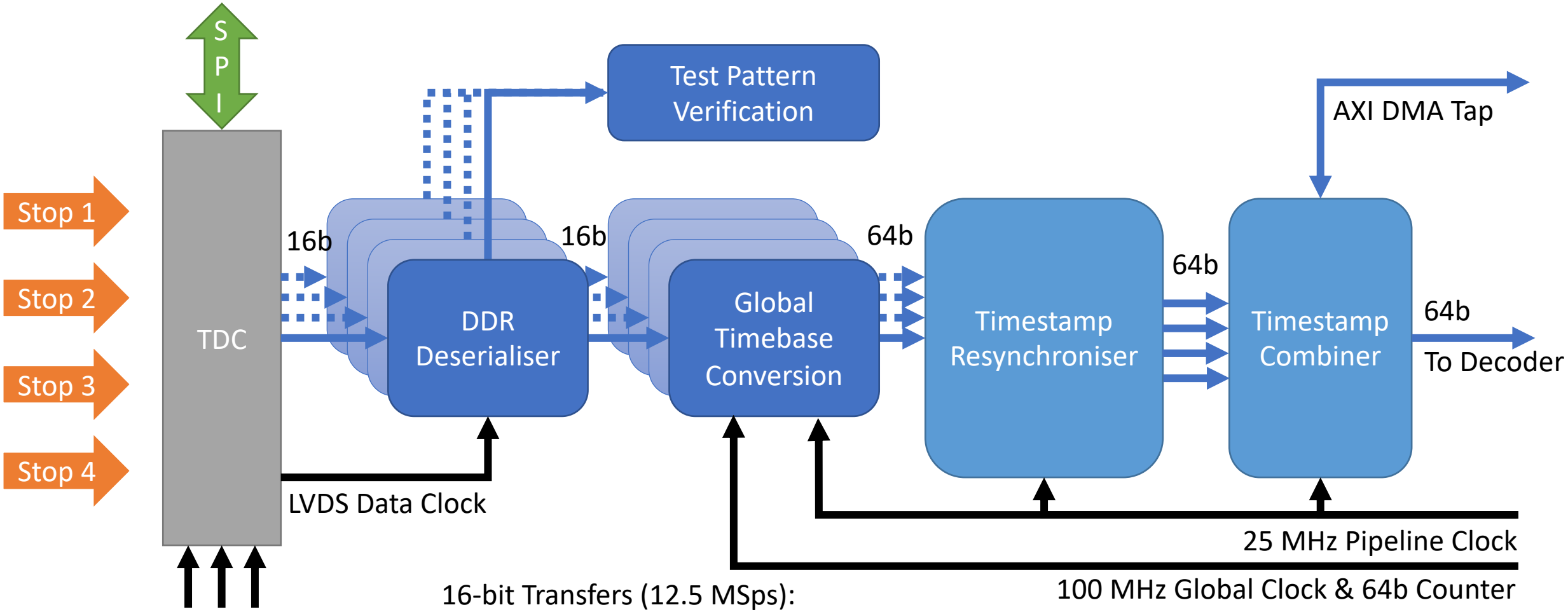
STAR lab

Space Telecommunications Astronomy Radiation

UF UNIVERSITY of FLORIDA

Backup Slides

TDC Timestamping Pipeline



- 12.5 MHz Reference Clock
- 3.125 MHz Index Reset Clock
- 100 MHz LVDS Data Clock

16-bit Transfers (12.5 MSps):

- 14 stop bits: $\frac{80\ \mathrm{ns}}{2^{14}} \cong 5\ \mathrm{ps}$
- 2 index bits: $80\ \mathrm{ns} \times 2^2 = 320\ ns\ \equiv 3.125\ \mathrm{MHz}$

Serialisation… already exists

PCIe x16 Interface

- The SerDes module is provided a 100 MHz reference
- It has an internal x20 PLL that locks to the reference
- At 100 MHz, it is “fed” a 20-bit binary number, emitted bit-by-bit at 2 GHz