

Constellation



A Flexible Control and Data Acquisition
Framework for Beamlines and Beyond

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for the EDDA collaboration
11th Annual MT Meeting, Darmstadt

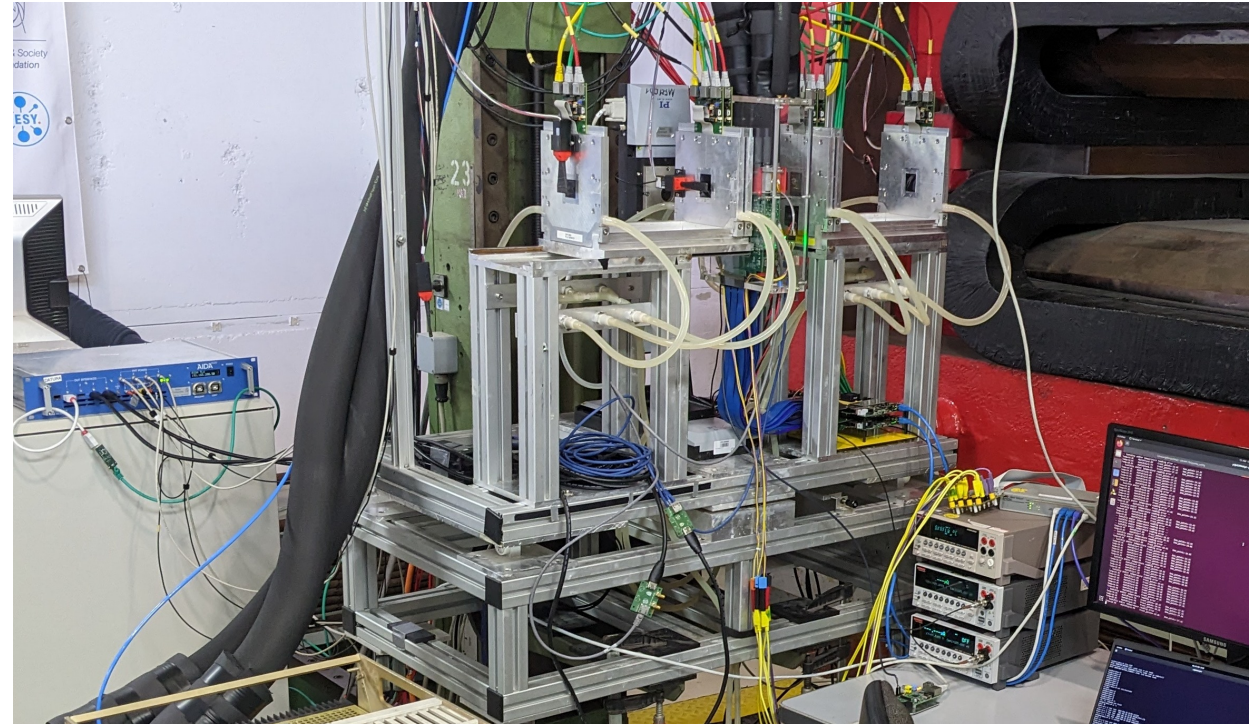
HELMHOLTZ

Prevas



Beamline Example: Testbeam at DESY

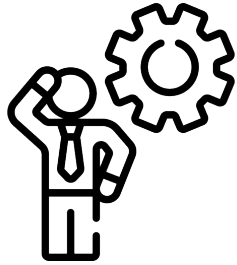
- Multiple devices required:
 - Device Under Test (**DUT**)
 - Beam **telescope** for tracking
 - Trigger Logic Unit (**TLU**) for synchronization
 - Timing Layer
 - Power supplies
 - Temperature sensors
 - ...
- Data Acquisition (DAQ) software spread across multiple computers



Example: Setup for the dSiPM test beam at DESY

Control Software at Beamline Setups

Challenges

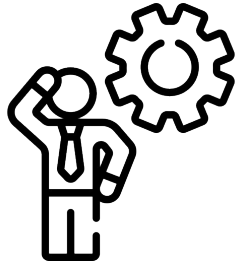


- Setup often deployed and used by students
- Different DAQ systems for different devices
- Frequent setup changes
- Integration depends on the facility
- Limited time for measurement (~ weeks)

=> Requires control software for synchronous operation

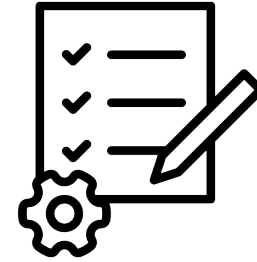
Control Software at Beamline Setups

Challenges



- Setup often deployed and used by students
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Requirements



- **Easy** to use
- **Fast integration** of new devices
- **Flexible** for many use-cases
- **Stable** operation and reliable error handling

Constellation



- Control and Data Acquisition Framework for dynamic small-scale experimental setups
- Comes with *batteries included*:
 - Control & configuration
 - Logging & telemetry
 - Failure handling
 - Network discovery
 - Data transmission
 - Hot-swappable components
- Extensive documentation & tutorials

The image shows two overlapping software windows from the Constellation project.

The top window, titled "Constellation Observatory v0.4 (Circinus)", displays a message log with the following data:

Time	Sender	Level	Topic	Message
2025-05-16 08:29:32	Caribou.dSiPM_1	WARNING	SATELLITE	1 keys of the configuration were not used: use_tlu
2025-05-16 08:29:32	Caribou.dSiPM_1	STATUS	FSM	New state: INIT
2025-05-16 08:29:32	Caribou.dSiPM_1	STATUS	FSM	New state: initializing

The bottom window, titled "Constellation MissionControl v0.4 (Circinus)", shows the system status and configuration. The Constellation is "tb22" with 10 Satellites in a "Running" state. The Run Identifier is "run_1" and the Run Duration is "00:00:08".

The Configuration section shows:

- Configuration: /home/stephan/dSiPM_tb.toml
- Log: (empty field)
- Run Identifier: run
- Sequence: 1

The Control section includes buttons for Initialize, Shutdown, Launch, Land, Start, and Stop.

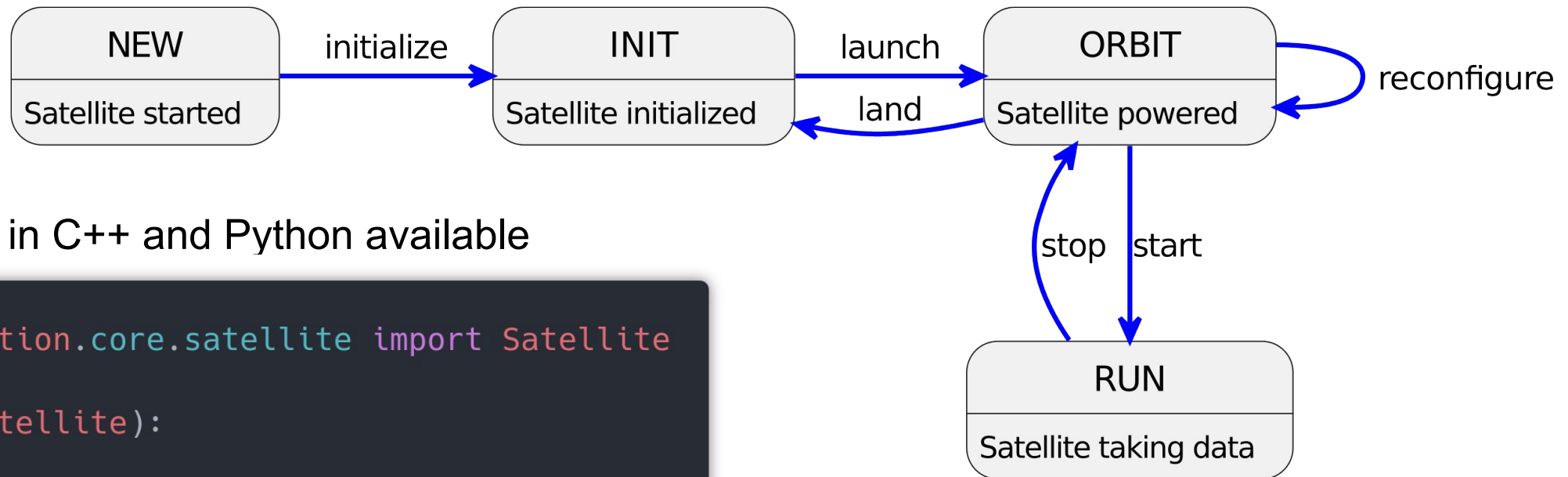
The Satellite connections table lists the following data:

Type	Name	State	Last response	Last message	Heartbeat	Lives
Adenium	Telescope	Running	SUCCESS	Satellite started run run_1 successfully	5000ms	3
AidaTLU	TLU	Running	SUCCESS	Satellite started run run_1 successfully	5000ms	3
Caribou	dSiPM_1	Running	SUCCESS	Satellite started run run_1 successfully	5000ms	3
EudaqNativeWriter	dSiPM_1	Running	SUCCESS	Satellite started run run_1 successfully	5000ms	3
EudaqNativeWriter	Adenium	Running	SUCCESS	Satellite started run run_1 successfully	5000ms	3
EudaqNativeWriter	TLU	Running	SUCCESS	Satellite started run run_1 successfully	5000ms	3
Influx	DB	Running	SUCCESS	transitioning	1100ms	3
Keithley	dSiPM_1	Running	SUCCESS	Satellite started run run_1 successfully	5000ms	3
Mattermost	Logger	Running	SUCCESS	Satellite started run run_1 successfully	5000ms	3
TempMon	N2	Running	SUCCESS	Satellite started run run_1 successfully	5000ms	3

Satellites



- Participants in the data acquisition are called **satellites**
- Operate **autonomously** (no central point of failure)
- Operation governed by a Finite State Machine (**FSM**)



- Implementation in C++ and Python available

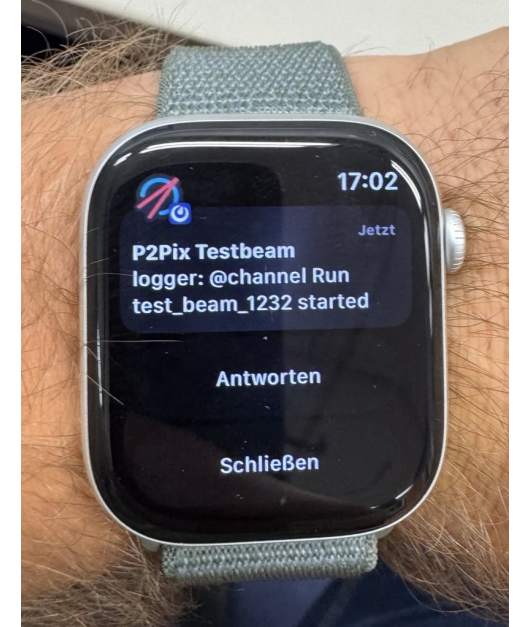
```
from constellation.core.satellite import Satellite

class Dummy(Satellite):
    pass
```

Application: Sensor Testing @ DESY II



- Testing of monolithic pixel sensor (e.g. H2M)
- Particle tracking with DESY-provided beam telescope
- Constellation highlights:
 - Backwards-compatible output to EUDAQ2 files
 - Mattermost notifications in case of failure
 - Online trigger rate monitoring via InfluxDB/Grafana



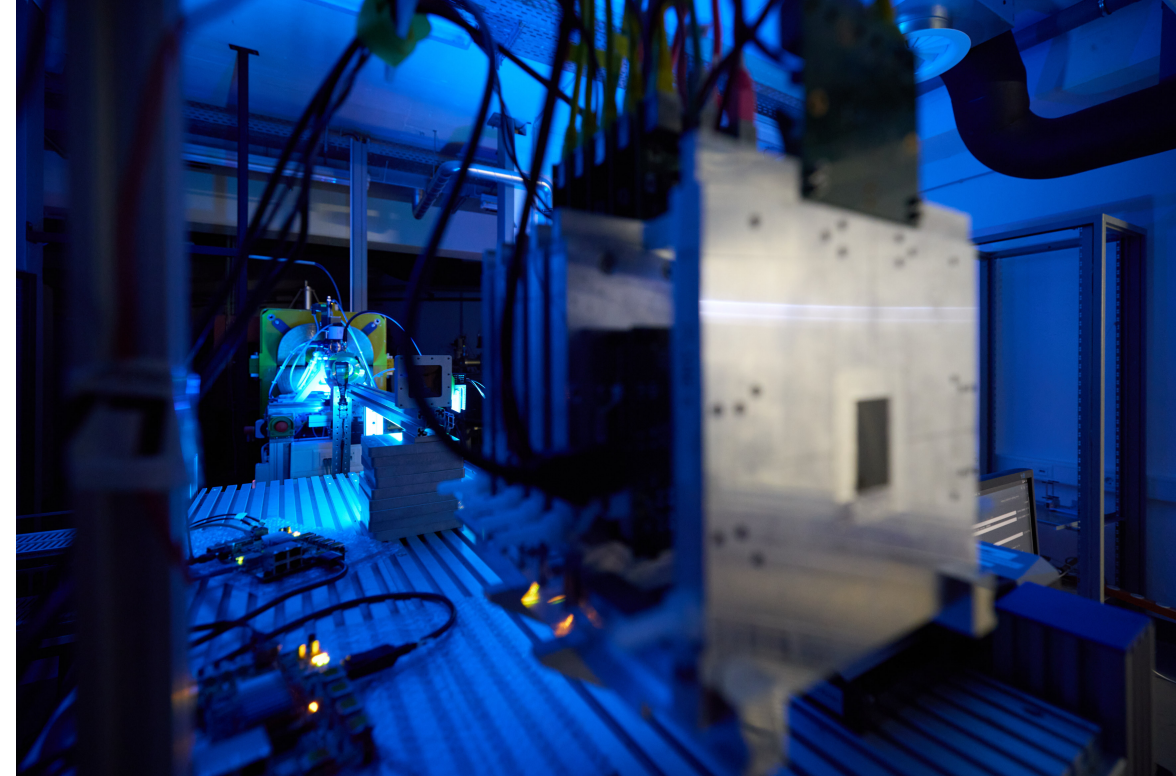
Constellation Mattermost notification on an Apple Watch (Lennart Huth)



Application: Beamline for Schools @ ELSA

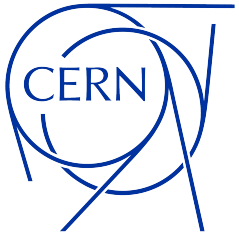


- Beamlines for Schools (BL4S) at the ELSA accelerator (University of Bonn)
- Worldwide competition for students to carry out small experiments at a beamline
- One team @ ELSA with 8 days of beam
- Integration provided by University of Bonn
- Setup operated by high school students
- Constellation highlights:
 - Easy-to-use graphical user interfaces
 - Fast integration of the setup



BL4S setup at ELSA (Rasmus Partzsch)

Application: Bent Crystal Characterization @ SPS



- Characterization of bent crystals for beam manipulation
- Timepix3 beam telescope @ SPS North Area
- Up to 14 motion stages for crystal movement and beam telescope alignment
- Constellation highlights:
 - Fast integration of the setup
 - InfluxDB/Grafana integration
 - Stable operation as user facility

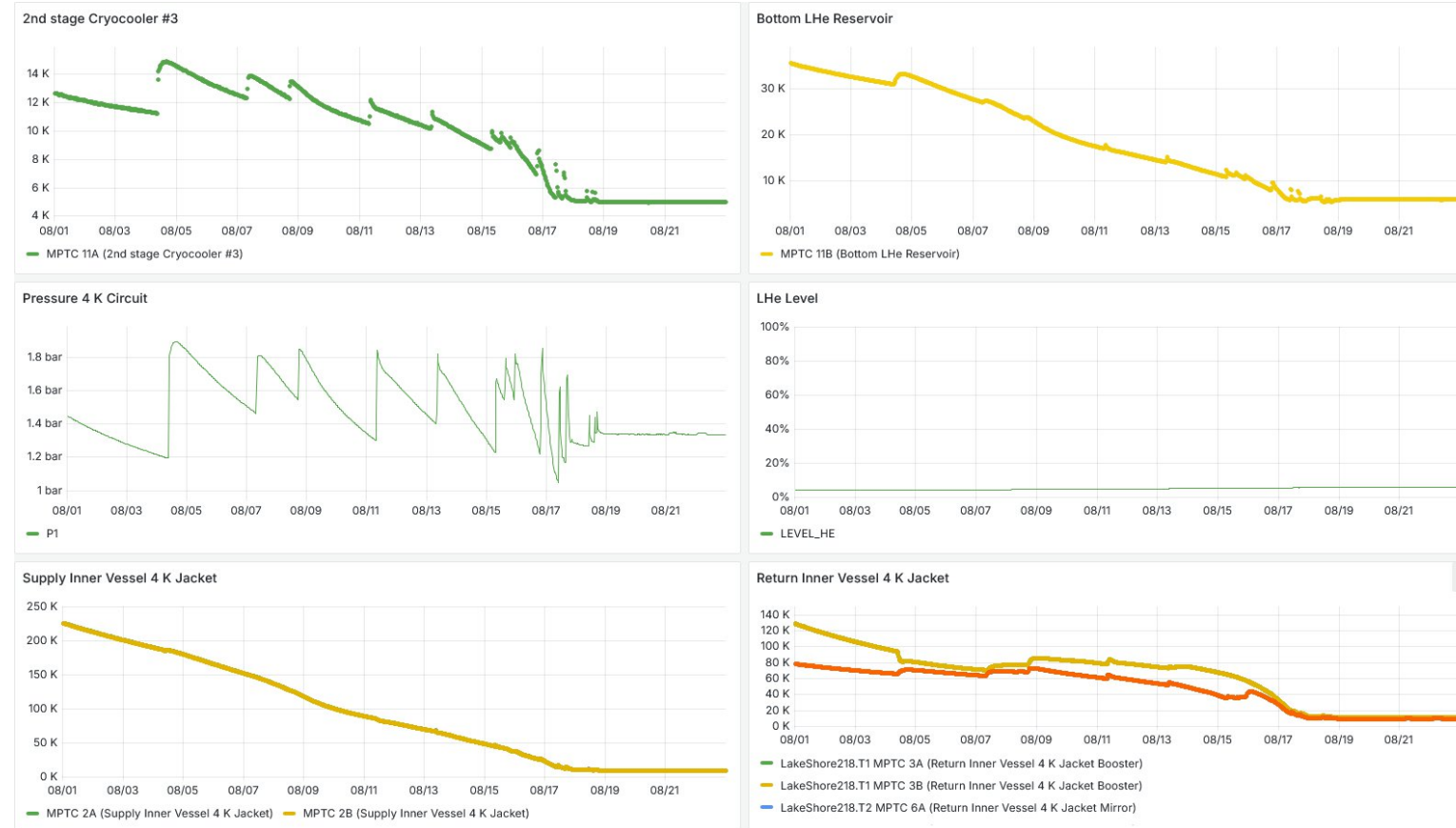


BIPXL setup at SPS (Justus Braach)

Application: MADMAX Cryostat @ UHH



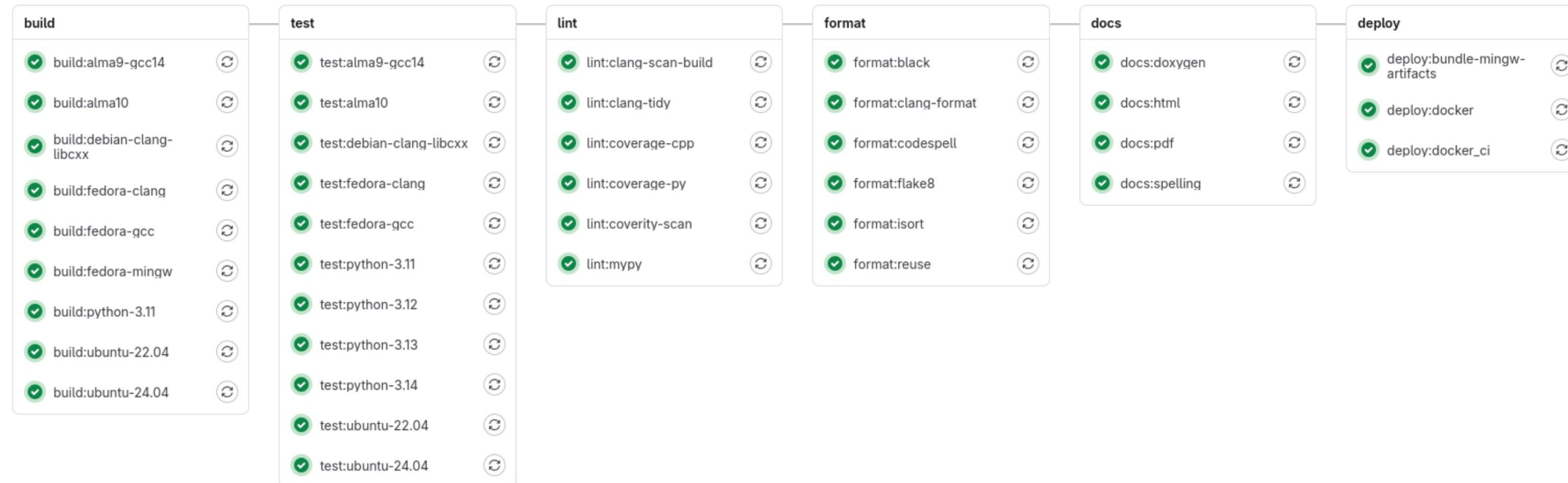
- Upcoming Dark Matter Experiment @ University of Hamburg
- Cryostat with liquid helium
- Constellation highlights:
 - InfluxDB/Grafana integration
 - Mattermost notifications
 - Stable operation



Online Monitoring of the MADMAX cryostat (David Leppla-Weber)

Project Status

- Fully open source under EUPL-1.2
- Available on DESY GitLab
- Currently version 0.6.1 (*Triangulum Australe*)
 - Mostly feature complete
 - Version 1.0 planned for spring 2026
- Continuously tested (~85% code coverage)
- Continuously deployed on PyPI, FlatHub and as Docker image



Patch Release 0.6.1 for Constellation Triangulum Australe

2025-10-08 Simon Spannagel, Stephan Lachnit, Hanno Perrey
[Releases](#)

This patch release contains a series of import bug fixes and minor improvements for our last release.

[Read more ...](#)

Constellation Preview Release 0.6

2025-09-24 Simon Spannagel, Stephan Lachnit
[Releases](#)

We are happy to announce the release of **Constellation version 0.6**, named **Triangulum Australe**.

[Read more ...](#)

Summary

- Constellation is a control and data acquisition framework tailored towards beamline and lab setups
- Framework with *batteries included*
- Extensive documentation
- Used in several beamlines and setups



A screenshot of the Constellation Operator Guide website. The page has a dark blue header with the Constellation logo and navigation links: News, Satellites, Operator Docs (highlighted), Application Development, and Framework Reference. A search bar is on the right. The main content area has a dark blue background. On the left is a 'Section Navigation' sidebar with links for 'Get started' (Installing from Flathub, PyPI, Source), 'Tutorials' (Starting & Controlling a Satellite, MissionControl, Observatory), 'Concepts' (The Constellation, Satellite, Controller, Operation, Logging, Telemetry, Data Processing), and 'How-To Guides'. The main content area features the title 'Constellation Operator Guide' and a welcome message. Below this is a 'See also' section with links to 'integrate their own hardware or develop new satellites' and 'development of Constellation'. At the bottom, it states the guide is structured in four parts: Getting Started, Tutorials, Concepts, and How-To Guides.

Backup

Mattermost Notifications

-  edda_spammer BOT 10:33
Mattermost.Logger connected as logger
-  Caribou.dSiPM_1 BOT 10:33 🔔 IMPORTANT ⓘ
@channel 1 keys of the configuration were not used: use_tlu
-  edda_spammer BOT 10:33
@channel Run run_3 started
-  edda_spammer BOT 10:33 🔔 IMPORTANT
@channel Interrupted! Previous state: RUN
-  TempMon.N2 BOT 10:33 🚨 URGENT ⓘ
@channel Critical failure: Temperature above critical threshold!

Write to EDDA SPAM

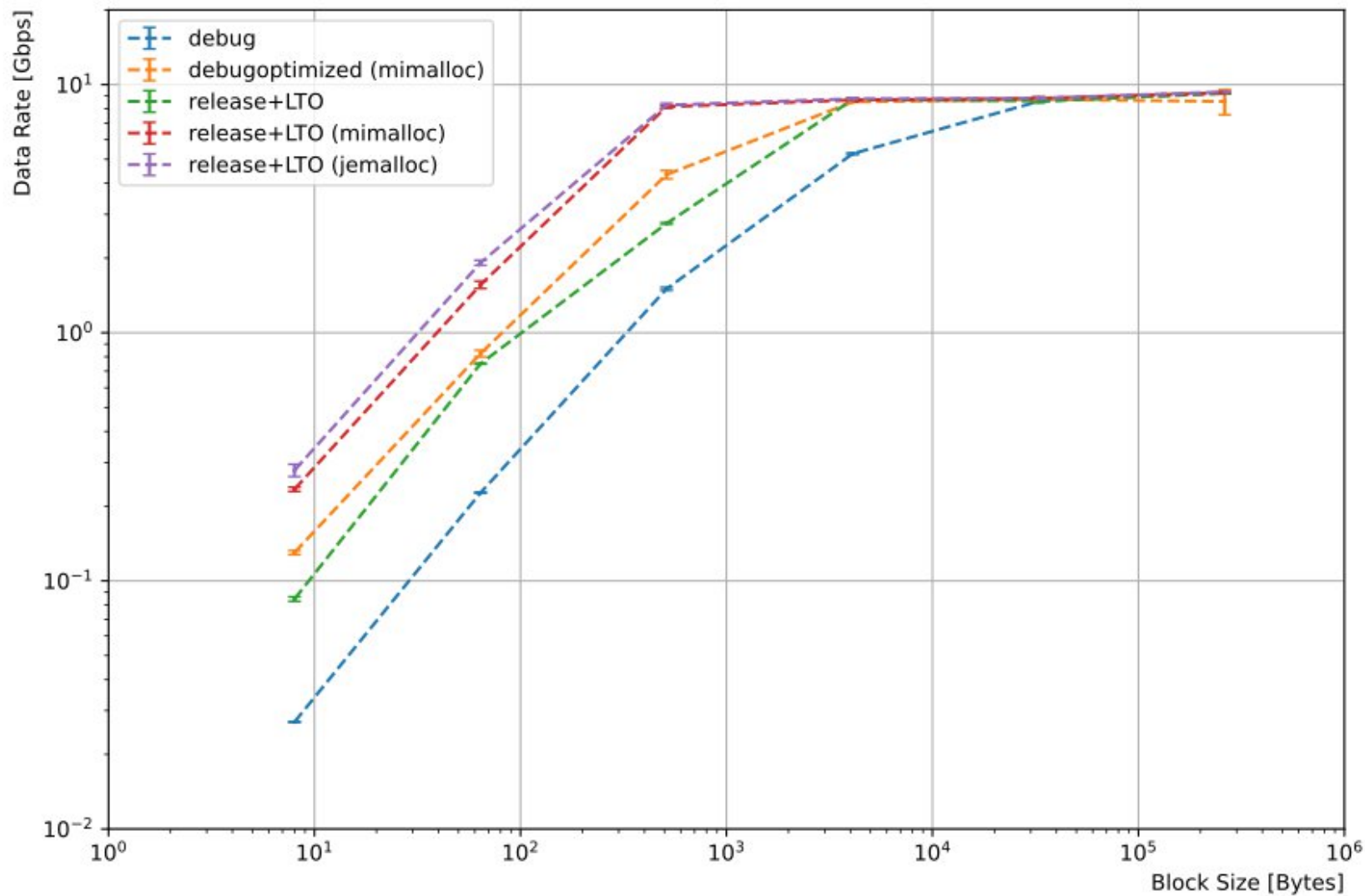
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Grafana Online Monitoring

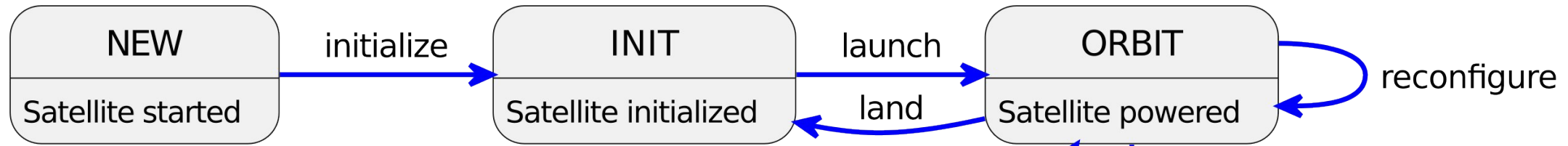


Data Transmission Speed

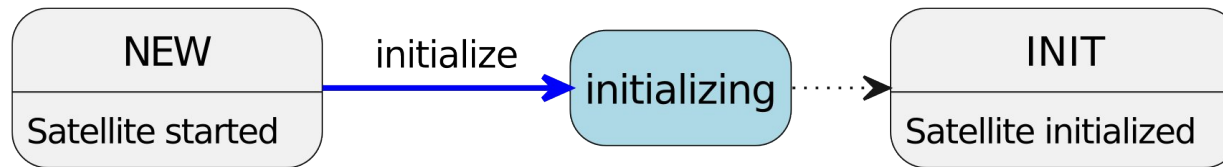


Satellite Finite State Machine

- Device is always in well-defined state



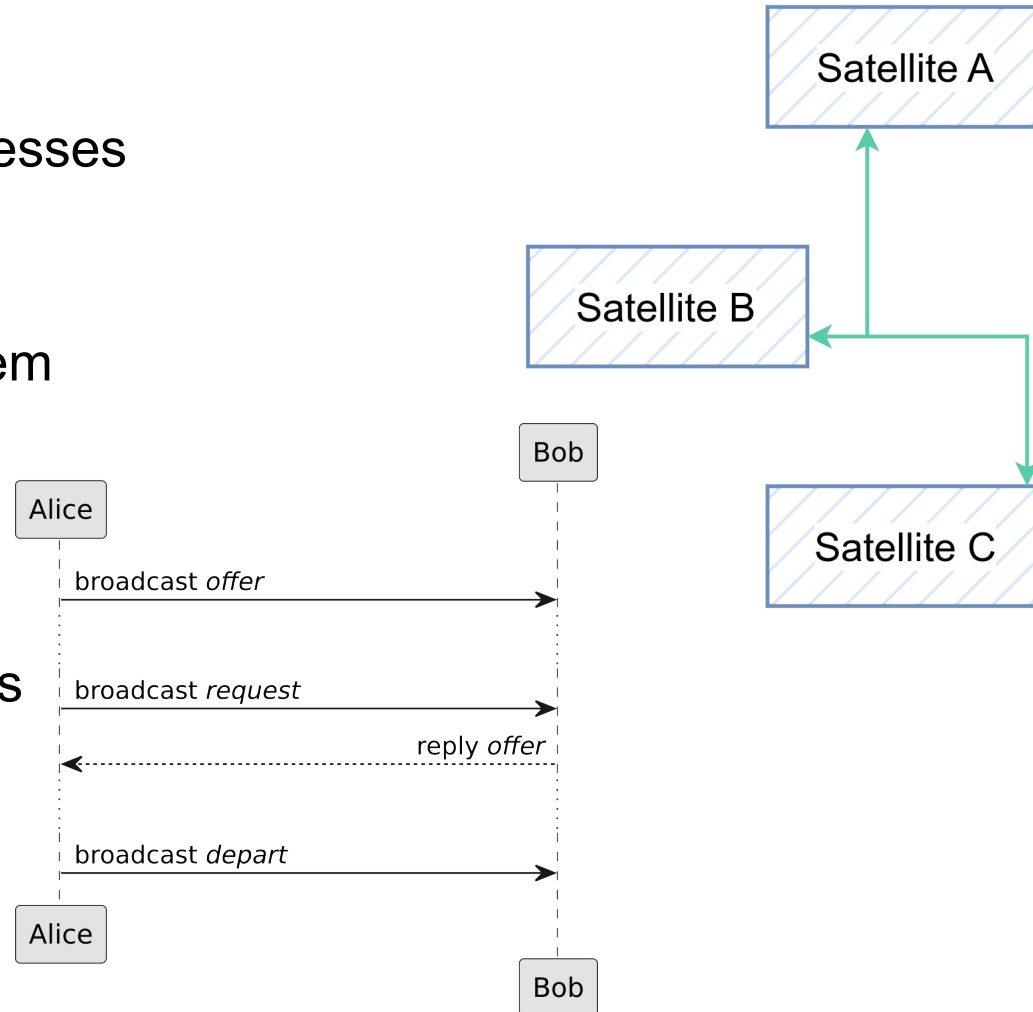
- Each transitions has to be implemented for the device
- Transitions have their own states for feedback on long operations



- Additional **SAFE** and **ERROR** states for error handling

Network Discovery

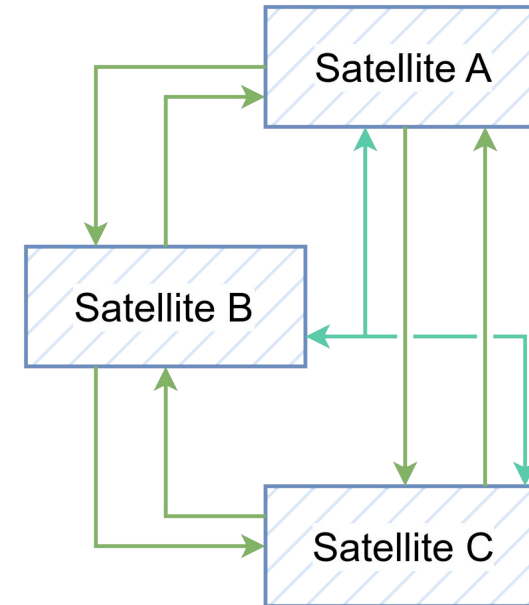
- Satellites in the local network are discovered automatically
- Advantages:
 - No need to assign fixed IP addresses
 - Simpler setup procedure
 - Allows for autonomy in the system
- Uses UDP broadcasts:
 - OFFER for provided services
 - REQUEST to search for services
- Ports assigned dynamically



CHP	Heartbeating
CSCP	Control
CMDP	Monitoring
CDTP	Data Transfer
CHIRP	Discovery

Autonomy

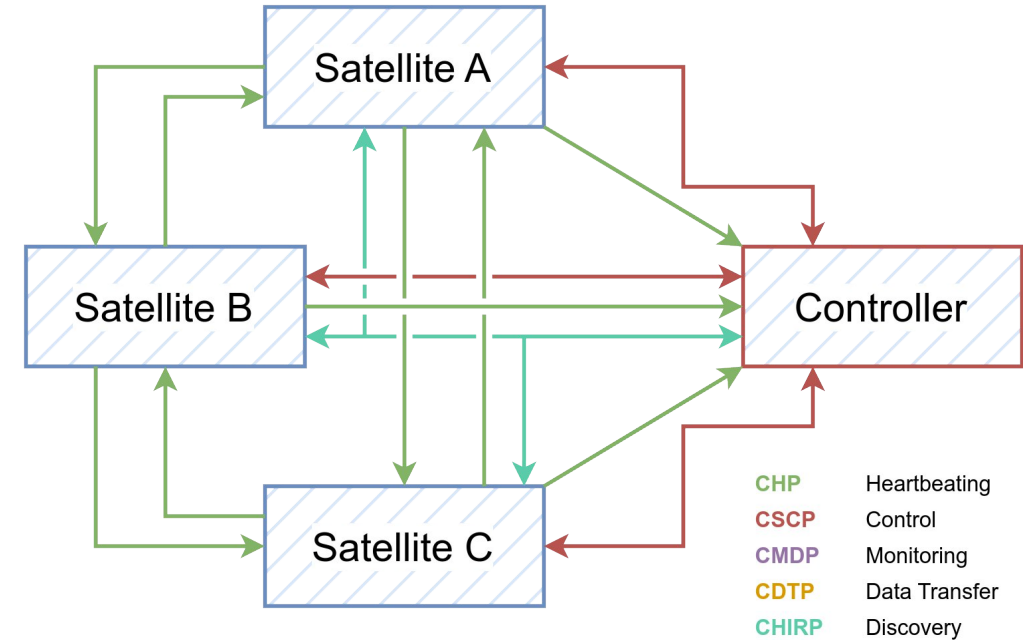
- Satellites emit regular “**heartbeats**”
- Heartbeats contain the current state of the satellite
- Each satellite connects to the heartbeats of the other satellites
- When another satellite sends a heartbeat with the **ERROR** state, satellites go to **SAFE** state
- When a satellite stops sending heartbeats (e.g. due to a crash), satellites go to **SAFE** state
- Heartbeats can also be used to monitor the states of the satellites with a stateless software



CHP	Heartbeating
CSCP	Control
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CHIRP	Discovery

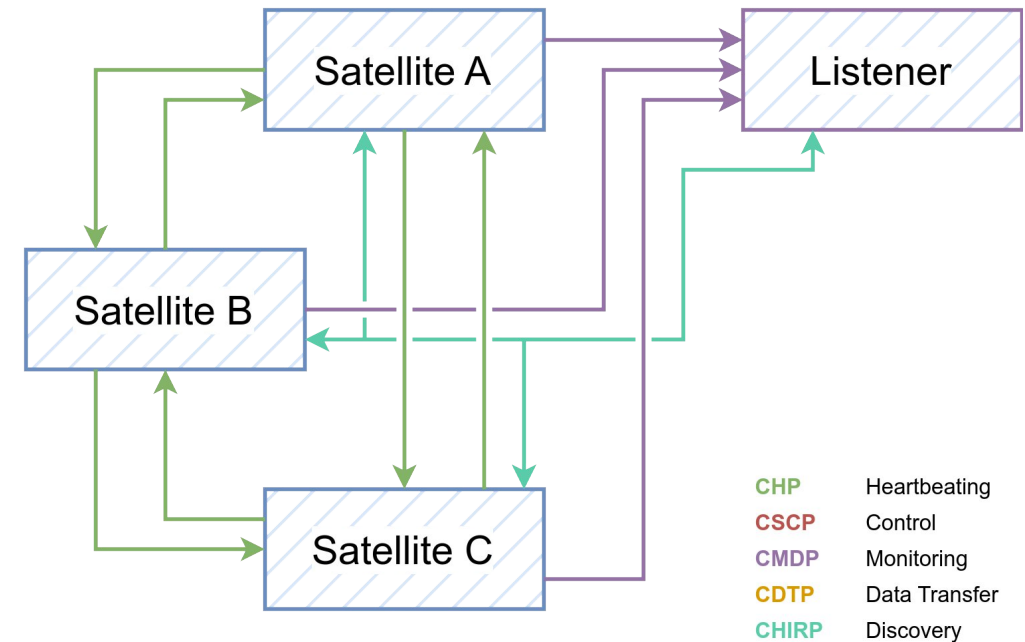
Control

- A controller joins the network:
 - Uses network discovery to find satellites
 - Connects to receive heartbeats
 - Uses heartbeats to monitor the state
 - Sends commands to a single or all satellites
- Client-server pattern for commands
- Controllers are stateless
- Custom commands are possible
e.g. read register values



Monitoring

- Satellites can publish telemetry and log messages
- A monitoring listener joins the network:
 - Uses network discovery to find satellites
 - Subscribes to relevant log messages or telemetry
- Publish-subscribe pattern
- Only subscribed monitoring data is actually transmitted
- Simple integration into third-party software like InfluxDB/Grafana or Mattermost



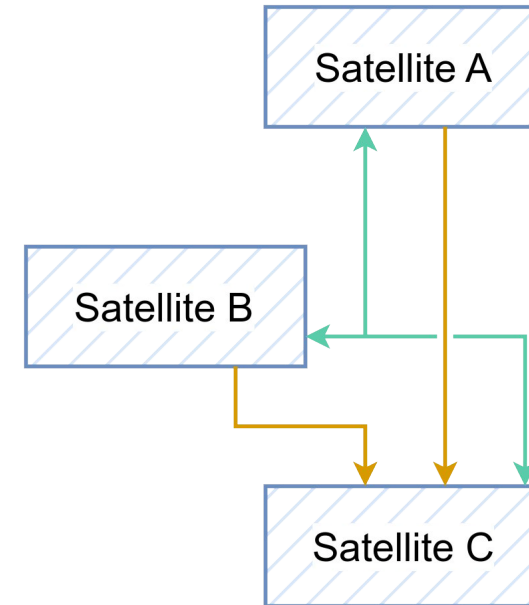
Data Transmission

- Sending data over the network can be useful:
 - Embedded system (e.g. Caribou)
 - Store all data in one place
 - Flexible Support for file format
 - EUDAQ2
 - HDF5



Caribou DAQ system

- Capable of >10 Gbps transmission throughput



CHP	Heartbeating
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