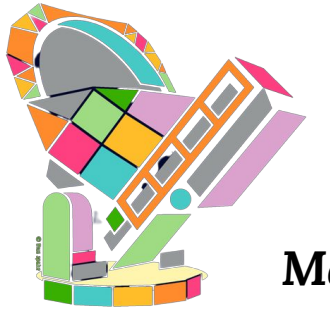
Testing the SPT-SZ Cryostat and Upgrading Control Software for use in Cosmic Microwave Background (CMB) Detector Investigations



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National Science Foundation Research Experiences for Undergraduates (REU)

Outline

1. The Cosmic Microwave Background (CMB)
2. The South Pole Telescope
3. The SPT-SZ Cryostat
4. Upgrades and Motivation
5. Current Control Software & Limitations
6. Installing Observatory Control System (OCS), InfluxDB and Grafana
7. Usage and Web Dashboard

1

The Cosmic Microwave Background (CMB)

What is it and how can we capture its signal?

The Big Bang

1927

George Lemaitre proposes the Big Bang Theory

1929

Edwin Hubble discovered that the distances to other galaxies are proportional to their redshifts

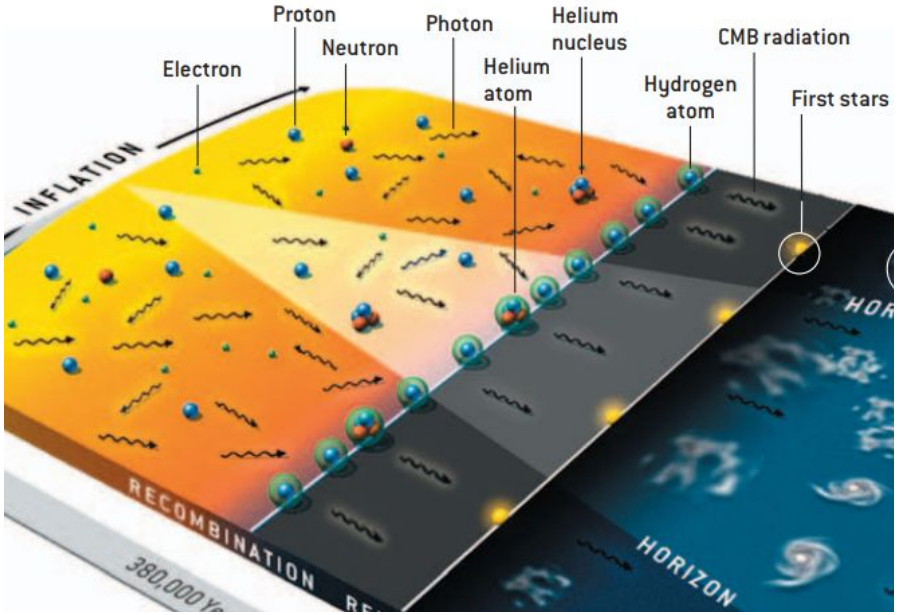
1965

Robert Wilson and Arno Penzias accidentally discovered the cosmic microwave background radiation–and shared a Nobel Prize in Physics for it in 1978

While the Big Bang cannot tell us about the pre-expansion state of The Universe, it reveals information about the evolution and growth of space from its birth all the way to the present day.

The Early Universe

- The CMB is a window to high energy physics occurring fractions of seconds after the Big Bang
- ~1e-36 seconds after the big bang, ~6,000 K
  - Universe was very bright
- As time went on:
  - The universe cooled
  - Protons and neutrons started to spread out
  - Hydrogen atoms formed
- ~380,000 years after the big bang, ~3,000 K
  - Photons are able to escape; the universe becomes “transparent”



Credit: Hu, Wayne and White, Martin. *The Cosmic Symphony*. Scientific American, 2003.

The CMB

- The Big Bang gives clues about the early Universe from the start of expansion to the present day

- Some photons that were emitted when the Universe became “transparent” are still traveling through space and can be detected in the present day–**this is the Cosmic Microwave Background**
  - The energy density of the CMB is 10x brighter than all of the other stars in the universe

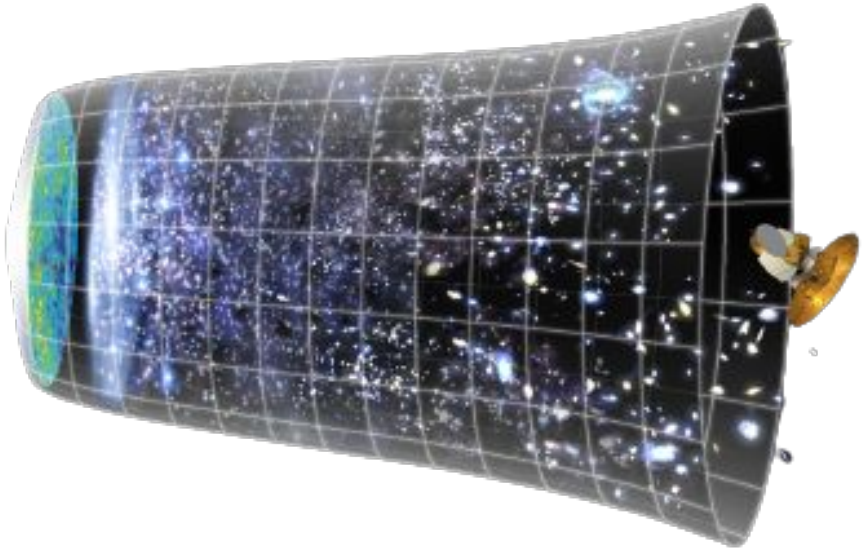


Image Credit: NASA / WMAP Science Team

The Expansion of the Universe

- Initial wavelength ~600 nm
  - ➢ 4,000 K blackbody
- Universe expanding = everything expanding
- Observable wavelength ~2 mm
  - ➢ 2.7 K blackbody

Credit: Ricardo Moreno, Susana Deustua, and Rosa M. Ros. *Expansion of the Universe*. NASE Publications.

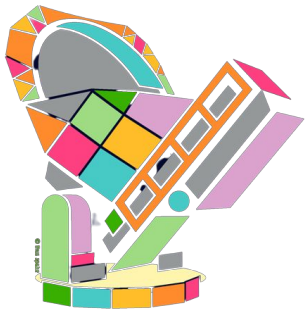
2

The South Pole Telescope at The University of Chicago

What questions does SPT try to answer?

THE SOUTH POLE TELESCOPE (SPT)

- 10 meter diameter telescope
- Microwave, millimeter and submillimeter wavelengths
- Arid and stable conditions at the South Pole
- Member of the Event Horizon Telescope (EHT) network



- The NSF Office of Polar Programs (OPP) “supports world class arctic and antarctic science through grants to researchers…providing polar facilities and operational support”

What kinds of questions does the SPT hope to answer?

Image Credit: *Screenshot*, pole.uchicago.edu

What kinds of questions does the SPT hope to answer?

- What is the origin of the Universe and what is it made of?
- What is the fate of the universe?
- What is dark energy?
- Are there undiscovered particle species in the early Universe?
- Is General Relativity correct in its definition of gravity? If not, what is gravity?
- When did the first astronomical objects and structures form, and how have they evolved?

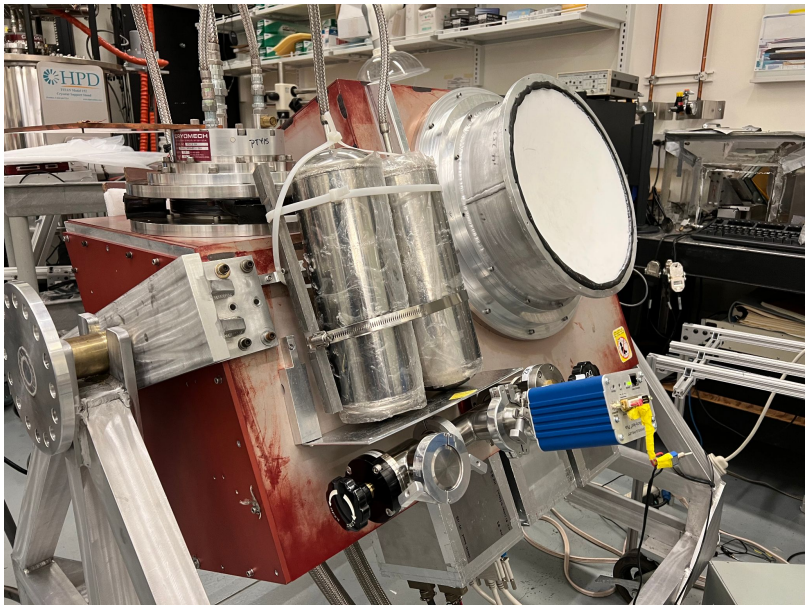
3

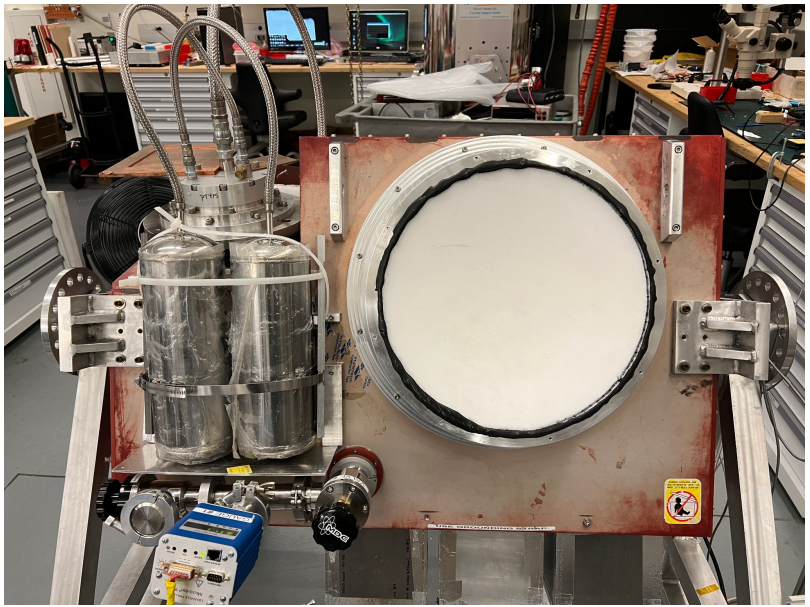
The SPT-SZ (Sunyaev-Zel`dovich) Cryostat

Components, function, and operation.

Cryostat Overview

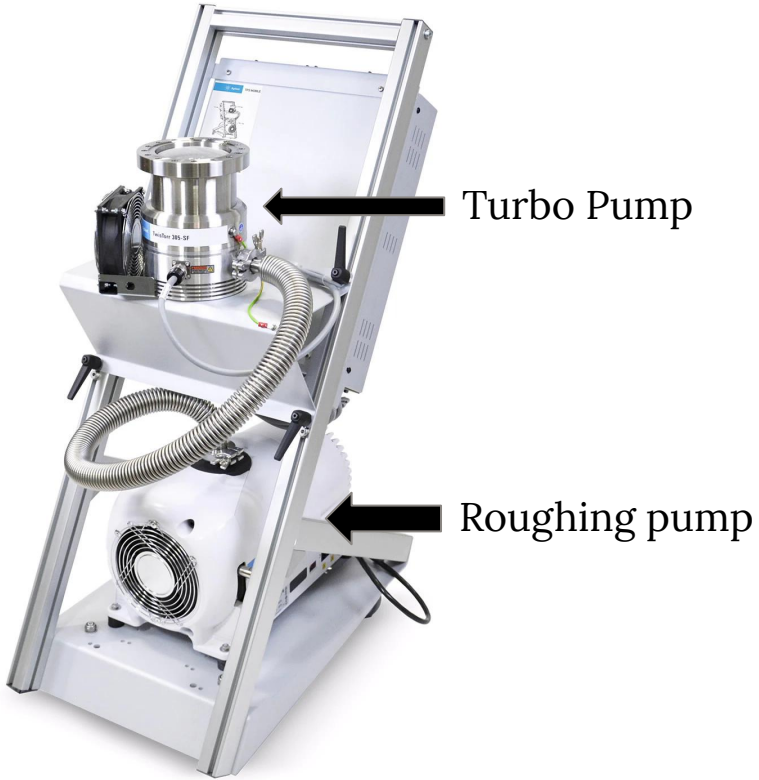
- **Cryostat**: a device used to maintain very low temperatures and house other devices under vacuum





Vacuuming System

- A vacuum inside of the cryostat is necessary to reduce noise and for the devices inside to get cold
  - ➢ Even heat conduction from air molecules can lead to issues
- When things get very cold, a self-maintaining vacuum called cryopumping is achieved
  - ➢ Pressures inside of the cryostat can get as low as ~1e-7 Torr because of this

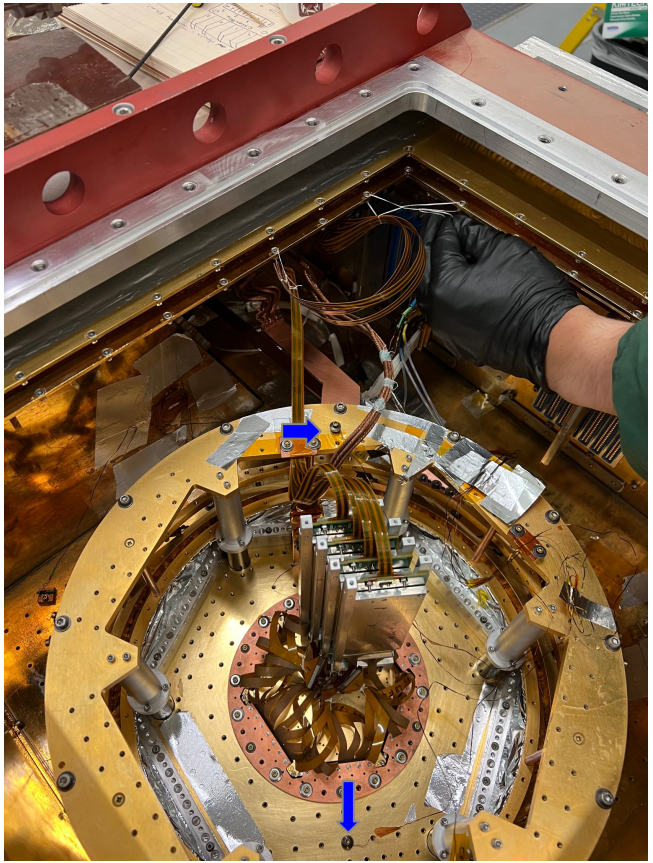


Cryostat Cooldowns

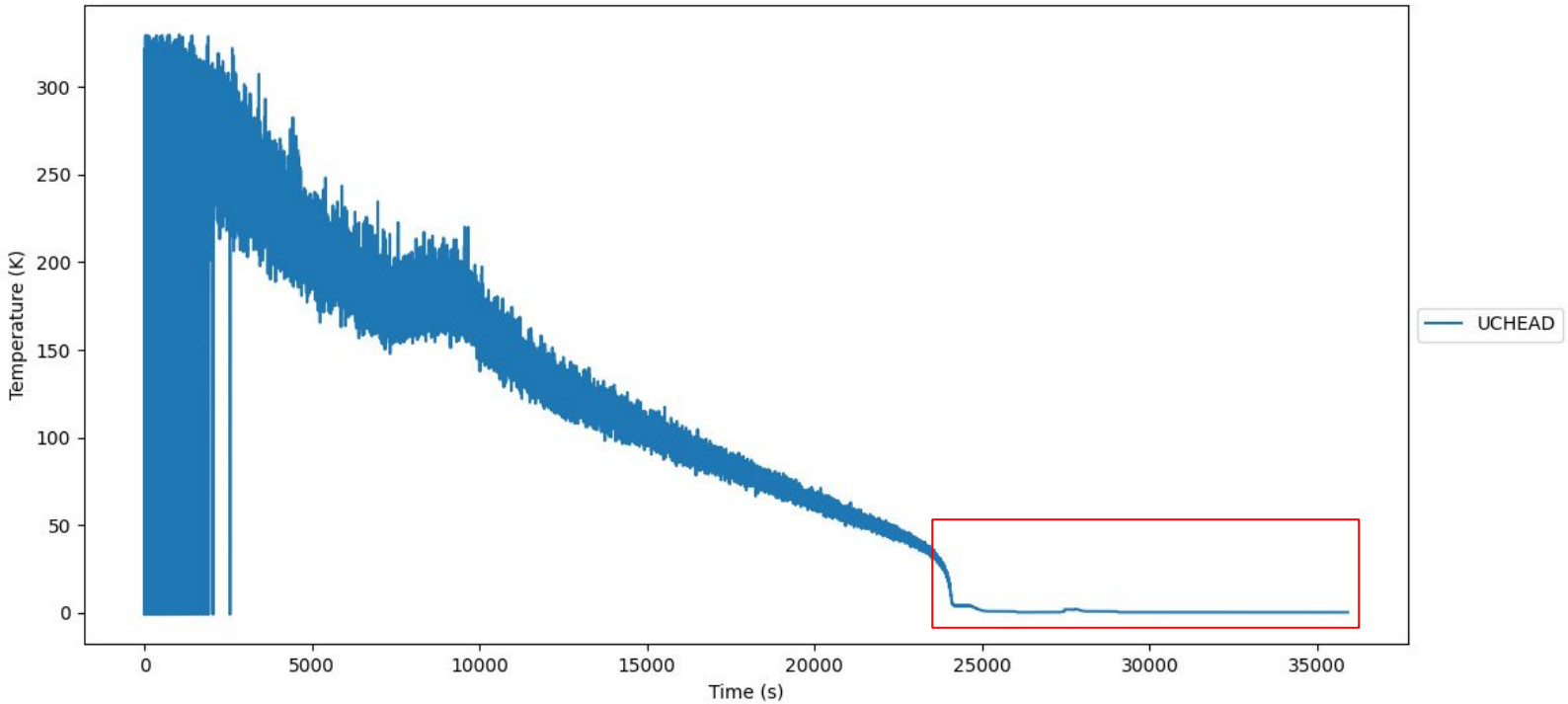
- Multistage cryostats
  - 300 K, 50 K, 4 K, and 300 mK at center
- Radiation shielding is used to separate the different layers
- Uses a pulse tube cooler
  - No cold moving parts, minimal vibrations
  - Takes advantage of the physical properties of different isotopes of helium: Helium-3 and Helium-4
- Superfluidity occurs between these two isotopes of Helium
  - Flow without resistance

Electronics

- CMB detectors are in the center of the cryostat
- Thermistors are used to read out temperatures
  - They allow us to monitor the temperatures from the outside
- We want to have a functioning cryostat for detector testing
  - We have been running test cooldowns to ensure things are working properly
- We ran three different cooldowns:
  - As the cryostat was when we arrived
  - Adding an additional filter
  - Adding the detector wafer



Measuring Base Temperatures



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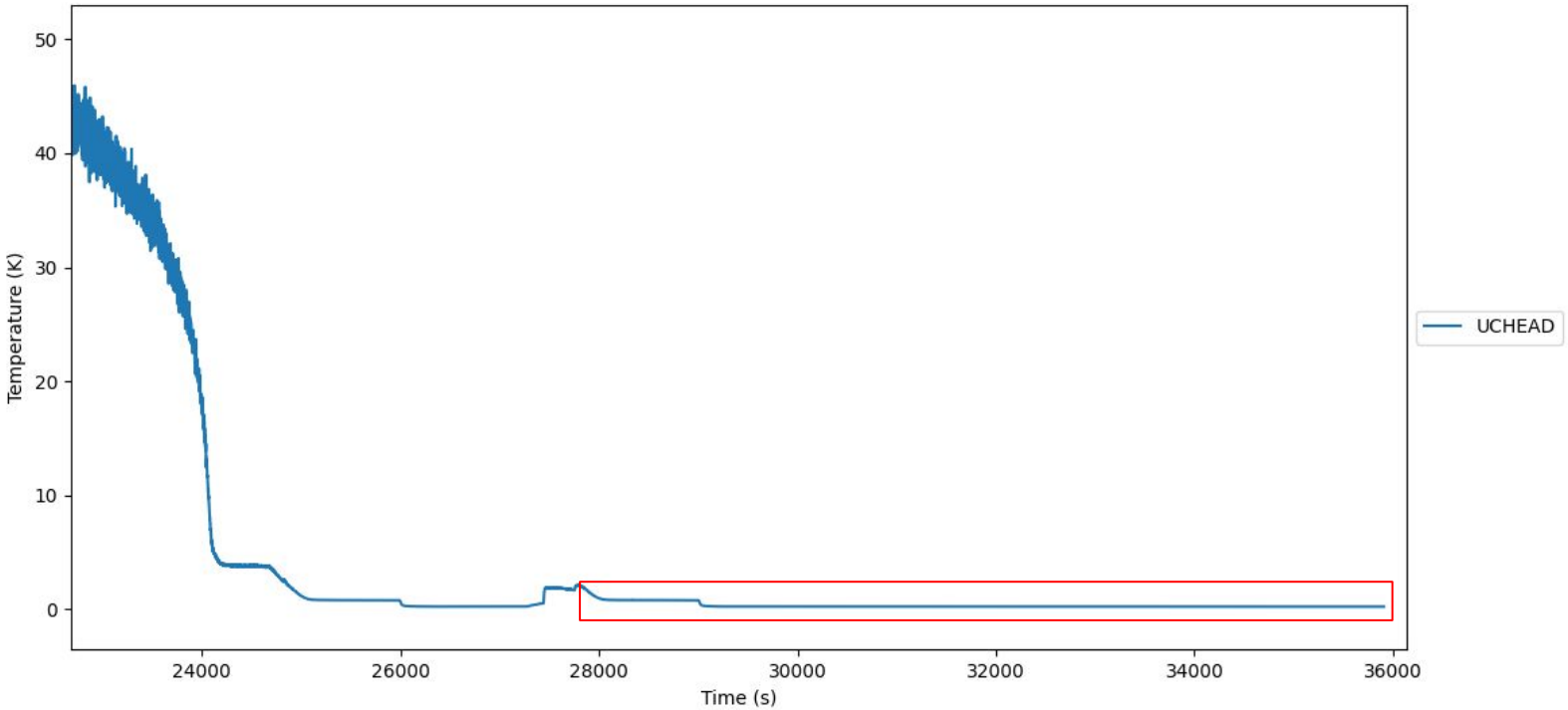
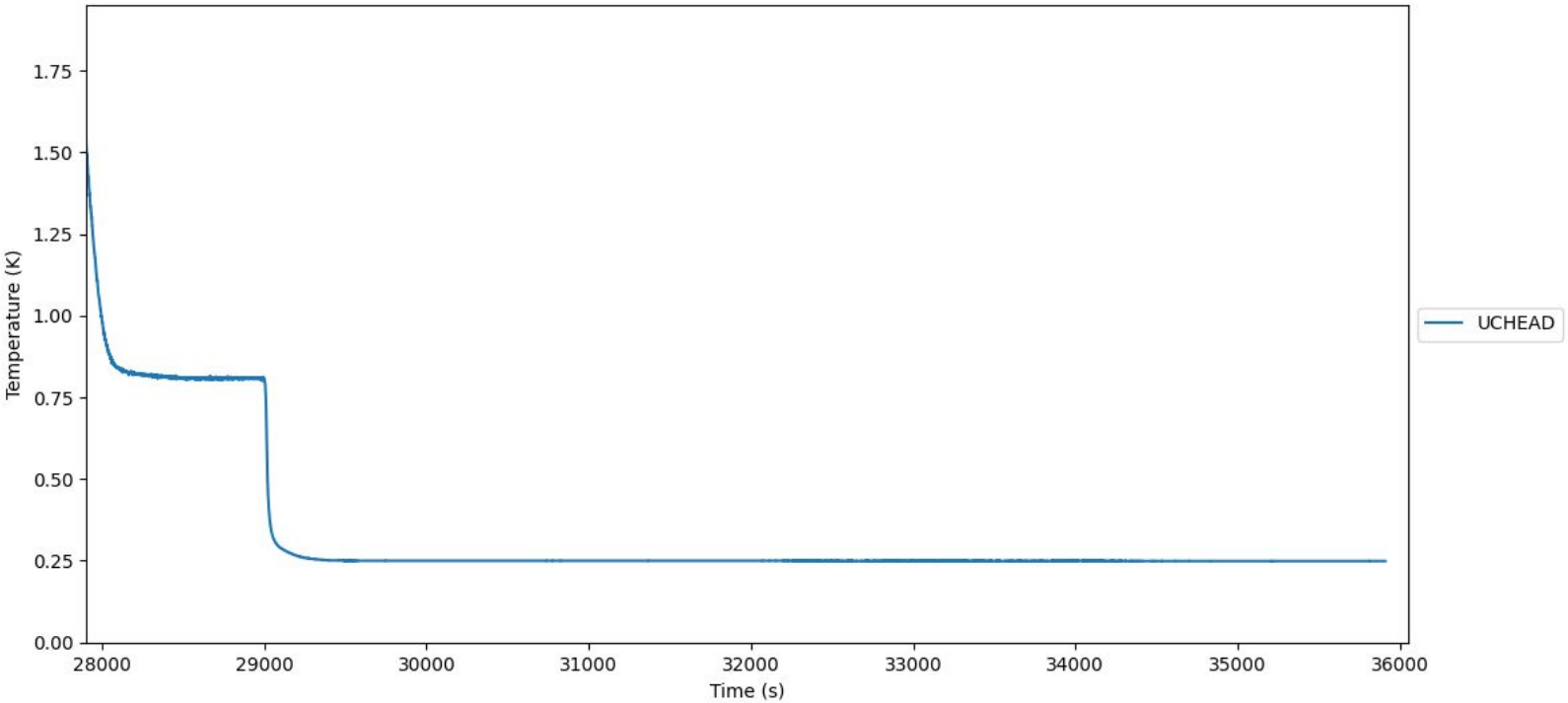


Measuring Base Temperatures



4 Motivations

Why are we working with the SPT-SZ cryostat in particular?

Motivations & Goals

- SPT-SZ was last modified in 2020
- Instrumentation summer school (next week)
  - Leak checking
  - Repeated cooldowns for monitoring
  - Pinning and thermometry checks
- Robust observatory control software already in existence
  - Centralize data collection and publish online
  - Test a new control system, OCS, for the South Pole Telescope
  - Previous software has not been updated in a long time

5

Current Control Software & Limitations

What kind of data do we collect? How do we do that?

Current Software

Before this summer, SPT-SZ was controlled using a series of Python scripts

↓

Though there is nothing wrong with the current operation, there is a need to streamline the pipeline

↓

SPT-SZ's transition to a detector testing and teaching device further emphasizes the need to make teaching and learning an easier experience overall

Limitations

Scripts must be run individually via the laboratory computer

Creating graphs requires queries and user input at any instance

Monitoring of temperatures, voltages, and other outputs can only be viewed from within the lab

↓

Above all, we want: a flexible data acquisition system, that is modern, that runs on the latest Python, is web-based, and reduces time spent in the lab via remote access capabilities

The Observatory Control System (OCS), InfluxDB and Grafana

6

What are the tools used in the new control and online publishing software?

OCS, InfluxDB and Grafana

Observatory Control System (OCS)

A distributed data acquisition software

- Web-based distributed system
- Designed to talk to multiple devices and "write" them all into one location
- Software developed by the Simons Observatory Group
- Link to API Documentation

Grafana

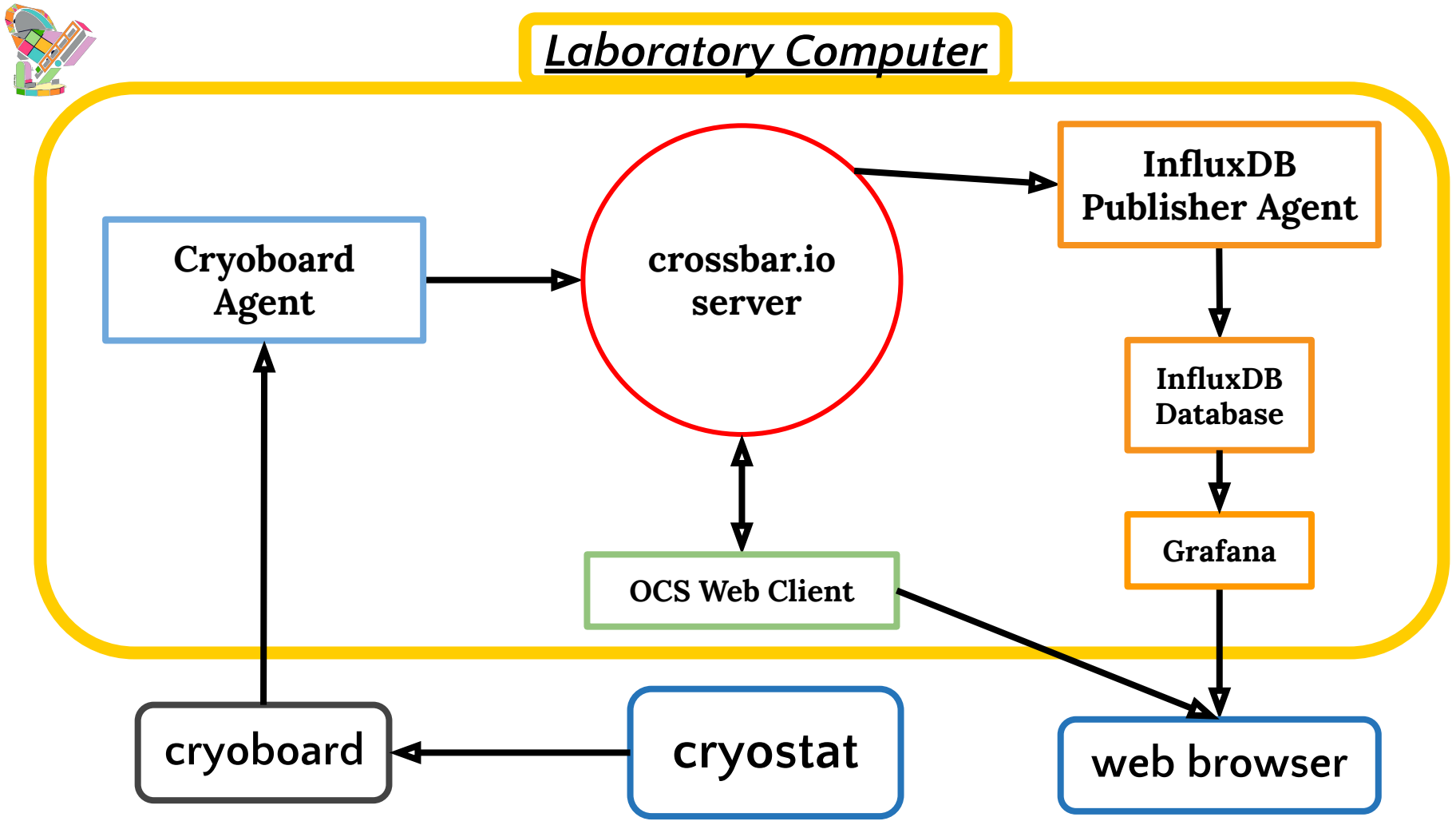
A web-based visualization and alerts platform

- Multi-platform
- Open source
- Customizable interfaces and Dashboard
- More than 285 plugins to work with

InfluxDB

A time series database

- Stores data from sensors, logs, etc... over long periods of time
- Communicates with Grafana to achieve remote data acquisition

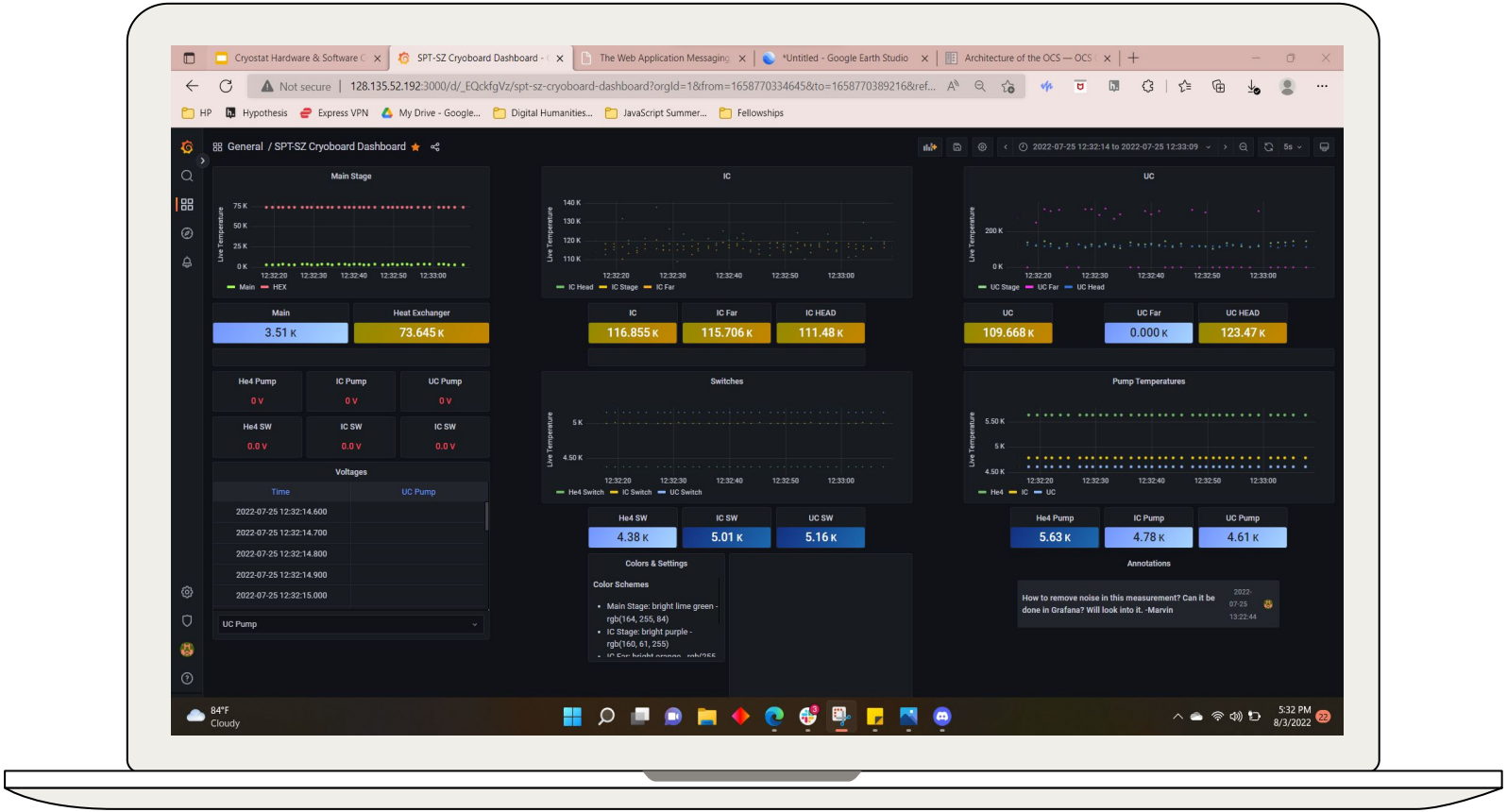

Laboratory Computer
Cryoboard Agent
crossbar.io server
InfluxDB Publisher Agent
InfluxDB Database
Grafana
OCS Web Client
cryoboard
cryostat
web browser

7

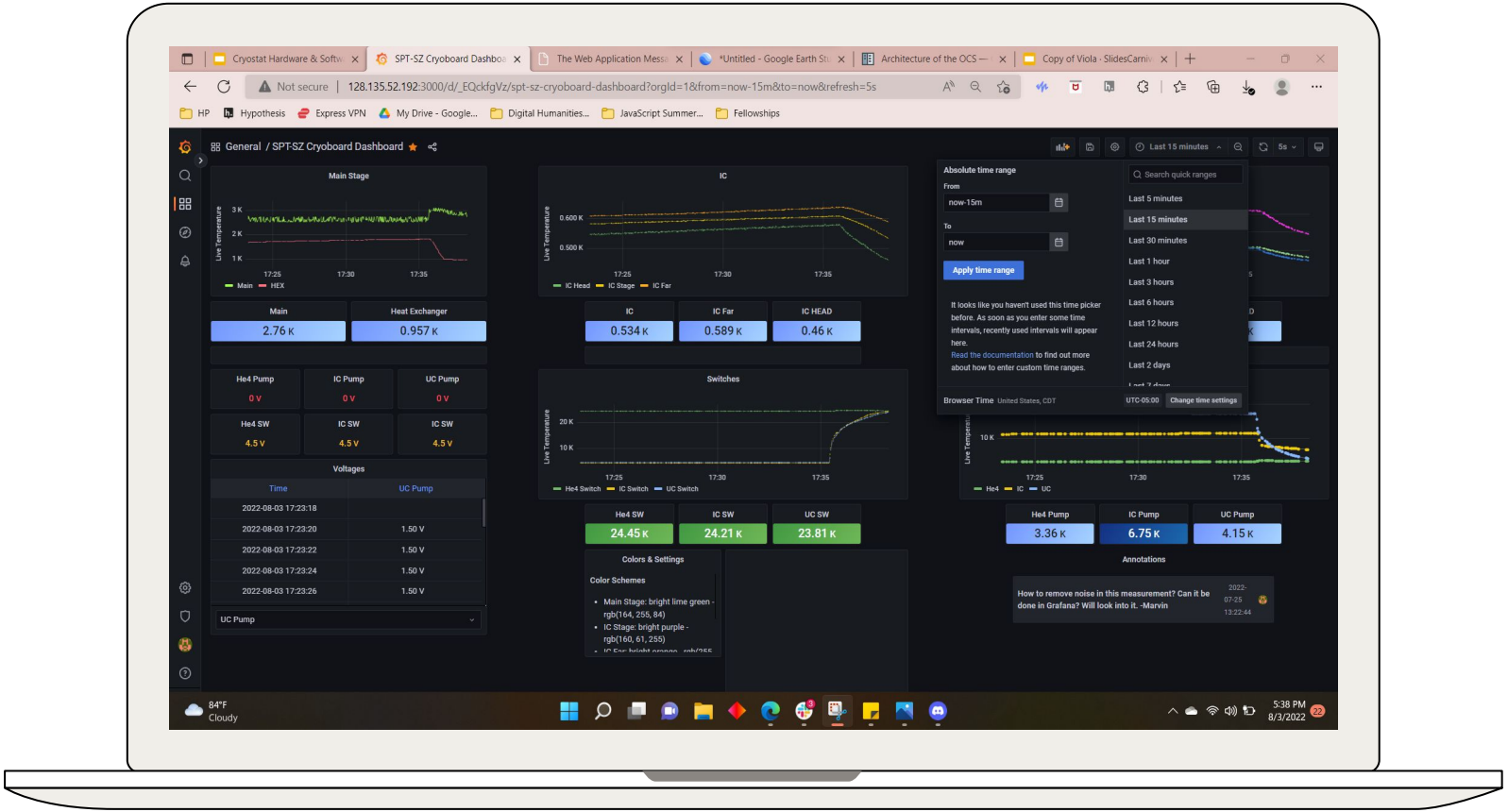
Usage and Web Dashboard

OCS and Grafana in practice.

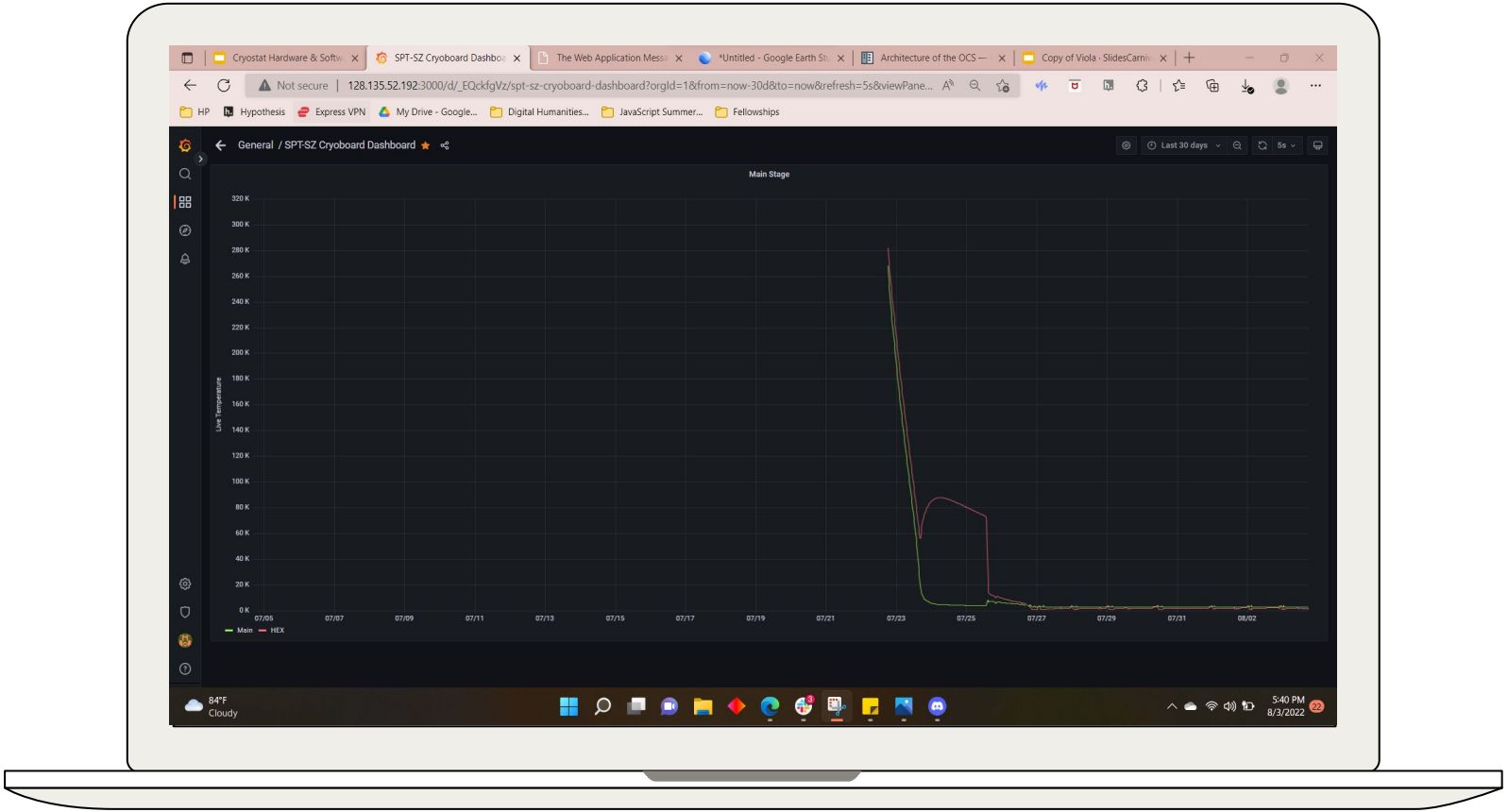
Grafana Online Dashboard



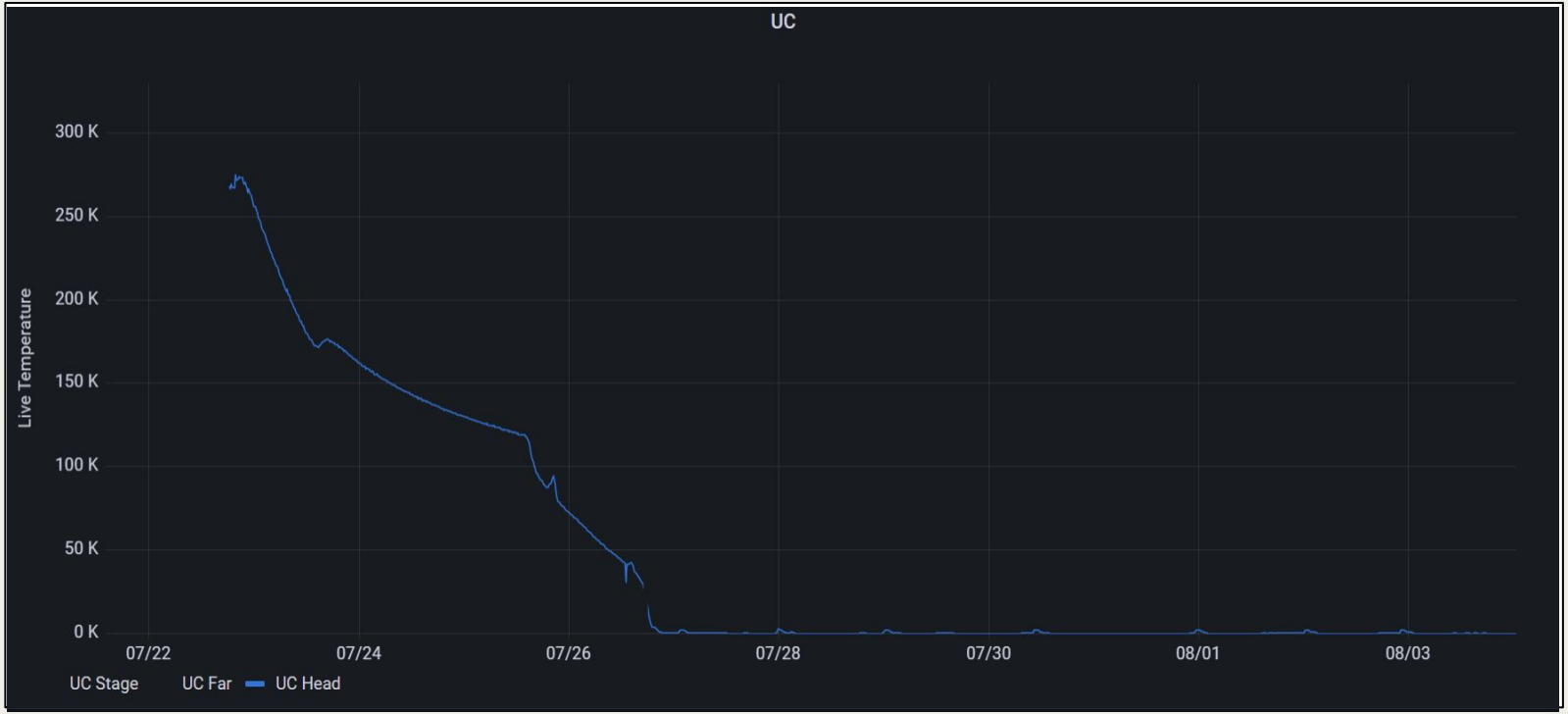
Viewing Historical Data



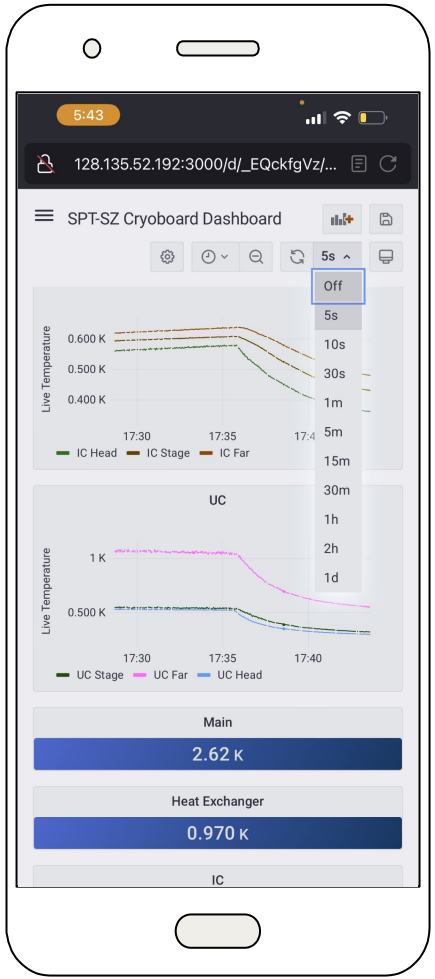
Panel Close-Up

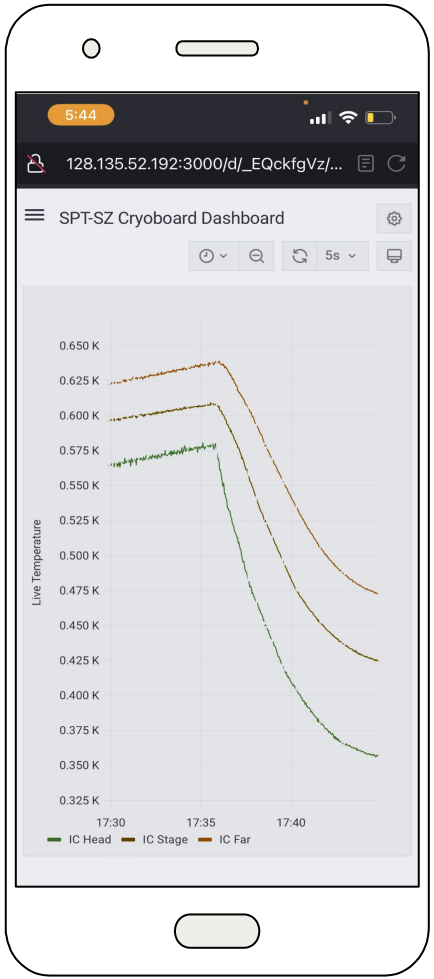


UC Stage Cooling Curve



Personal Devices





Thanks!

Any questions?

Acknowledgments

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Credits

Special thanks to all the people who made and released these awesome resources for free:

- Presentation template by SlidesCarnival
- Photographs by Unsplash

Sources (need to reformat, but placing links in here for now)

SPT

- The Department of Astronomy and Astrophysics | South Pole Telescope (uchicago.edu)
- SPT (uchicago.edu)
- South Pole Telescope | University of Chicago Global (uchicago.edu)
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