Event Horizon Telescope

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MIT Haystack Observatory

SA3CC Meeting | April 2024

About Me

- Started at MIT Haystack Observatory 2003
  - IT Manager and Research Engineer
    - Project operations/deployment/support
- Joined EHT project 2009
  - Commissioning team / Station operator
    - CARMA, LMT, SPT, and NOEMA
  - System repairs and coordination
  - Technical Operations
    - Remote support


CARMA

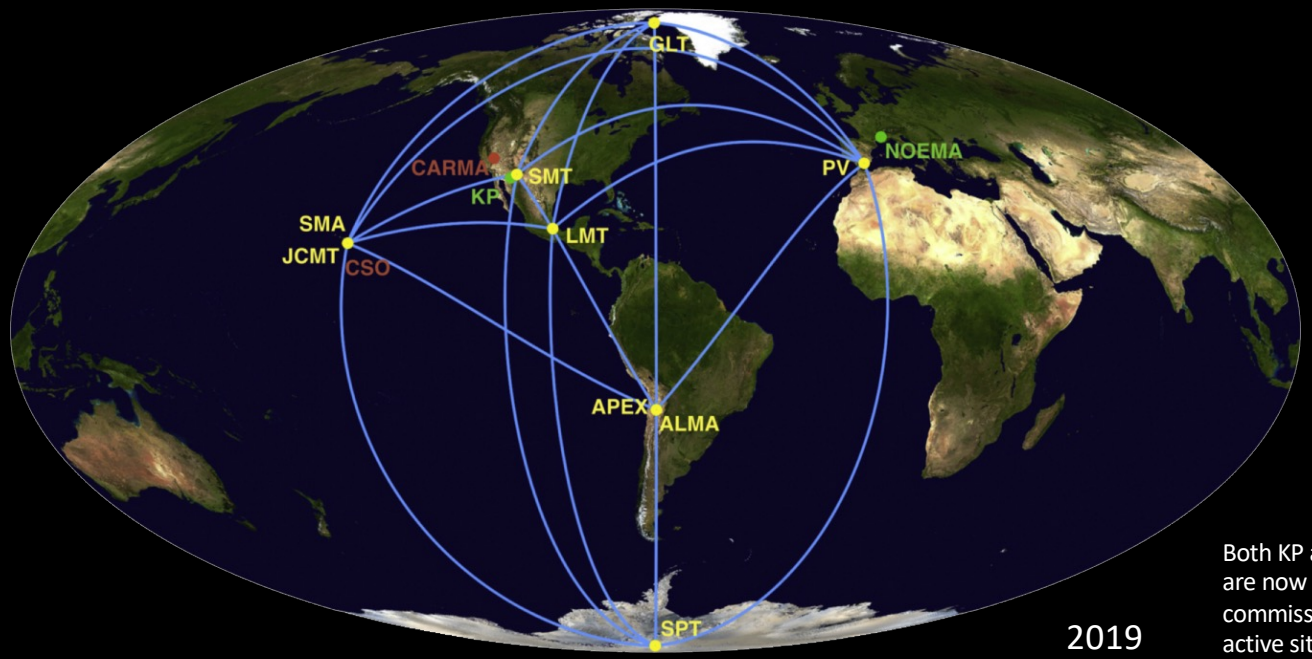

LMT


SPT


NOEMA

The EHT

The Event Horizon Telescope (EHT) is an array of millimeter and sub-millimeter wavelength telescopes using Very Long Baseline Interferometry (VLBI). The array spans the world creating a telescope with an effective Earth-sized aperture.



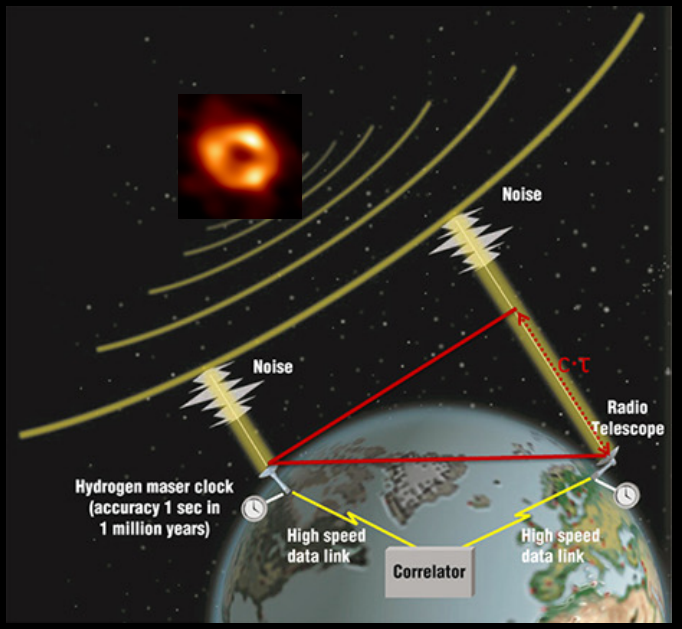
2019

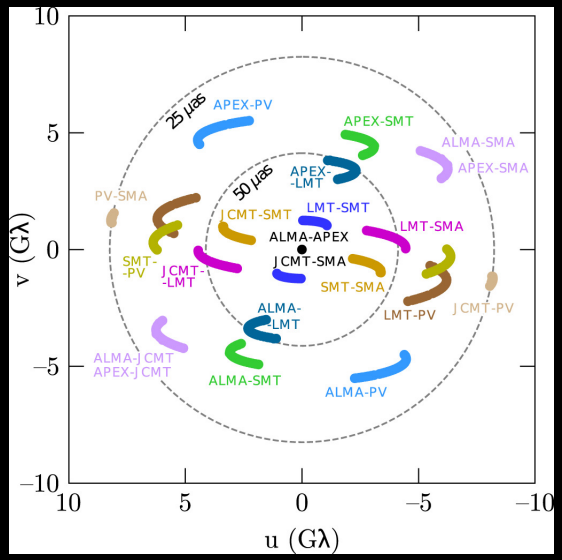
Both KP and NOEMA are now commissioned and active sites

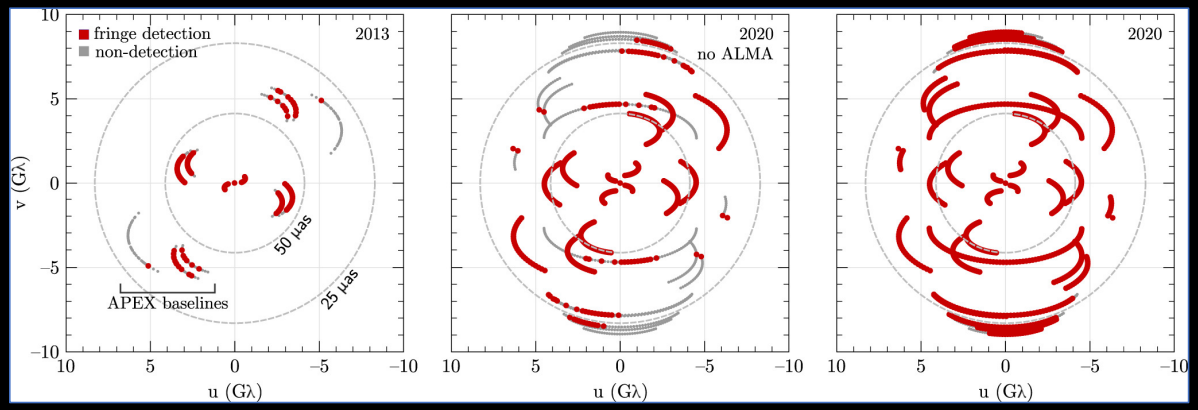
The EHT

Each pair of stations within the array creates a baseline covering the effective Earth-size aperture (bottom left)

Phased array stations like ALMA makes noticeable improvements to the observation coverage (bottom right)







The EHT

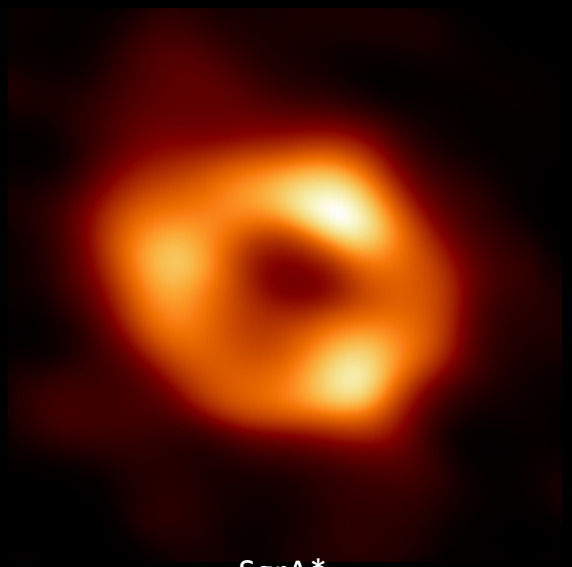
The EHT VLBI backend receives the broadband signal, digitizes it, and records onto data modules.

The data is then shipped to the MIT Haystack Observatory Correlator in Massachusetts, USA and the Max-Planck Institute for Radio Astronomy Correlator in Bonn, Germany for processing.

The EHT

The correlated data is then put through calibration algorithms to further reduce the data products. Imaging techniques are applied to the calibrated data to generate images such as super massive black holes.

M87



SgrA*

The EHT Papers

First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole
- The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L1

First M87 Event Horizon Telescope Results. II. Array and Instrumentation
- The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L2

First M87 Event Horizon Telescope Results. III. Data Processing and Calibration
- The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L3

First M87 Event Horizon Telescope Results. IV. Imaging the Central Supermassive Black Hole
- The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L4

First M87 Event Horizon Telescope Results. V. Physical Origin of the Asymmetric Ring
- The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L5

First M87 Event Horizon Telescope Results. VI. The Shadow and Mass of the Central Black Hole
- The Event Horizon Telescope Collaboration *et al.* 2019 *ApJL* **875** L6

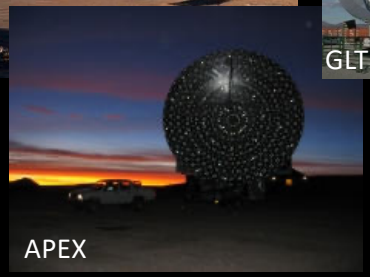
First M87 Event Horizon Telescope Results. VII. Polarization of the Ring
- The Event Horizon Telescope Collaboration *et al.* 2021 *ApJL* **910** L12

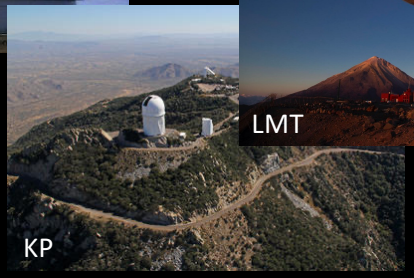
First M87 Event Horizon Telescope Results. VIII. Magnetic Field Structure near The Event Horizon
- The Event Horizon Telescope Collaboration *et al.* 2021 *ApJL* **910** L13

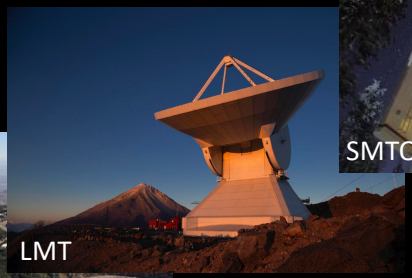
EHT Campaigns

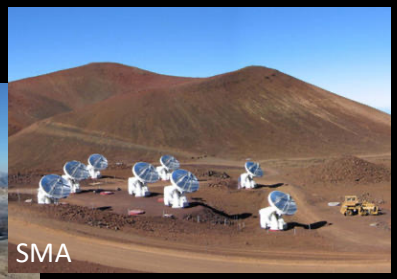
EHT2024 Observing Campaign

April 04 – 15, 2024
Observed 7 of the nights
11 sites participated
(ALMA, APEX, GLT, IRAM30m, JCMT, KP, LMT, NOEMA, SMA, SMTO, and SPT)









EHT 2024 Campaign

Campaign notes:

- Observations were at 230GHz, 260GHz & 345GHz
- Dual pol and double side band
- Station recorders at 64Gb/s
- Collecting about ~2PB raw data per station

Campaign staffing:

- Sites staffed with EHT observers and specialists
- Array Operations Center (AOC) staff located at “ground” level to monitor operations
- Technical Operations Support staffed for remote support during prechecks and operations

Network and data transport activities:

- The VLBI fringe test
- Real-Time Station monitoring during observations
- Remote access for operations and support

EHT Network and Data Transport Activities

The VLBI fringe test (January 2024):

- Stations coordinate a target source and send back a small sample of data via networks to a Correlator to confirm fringes
- There are many variables that require precise configuration that can only be confirmed via a fringe test
- This confirmation is a very strong indicator that a station configuration, timing, and setup is good
- Fringe tests can save a station from misconfiguration and “bad data” for an entire campaign

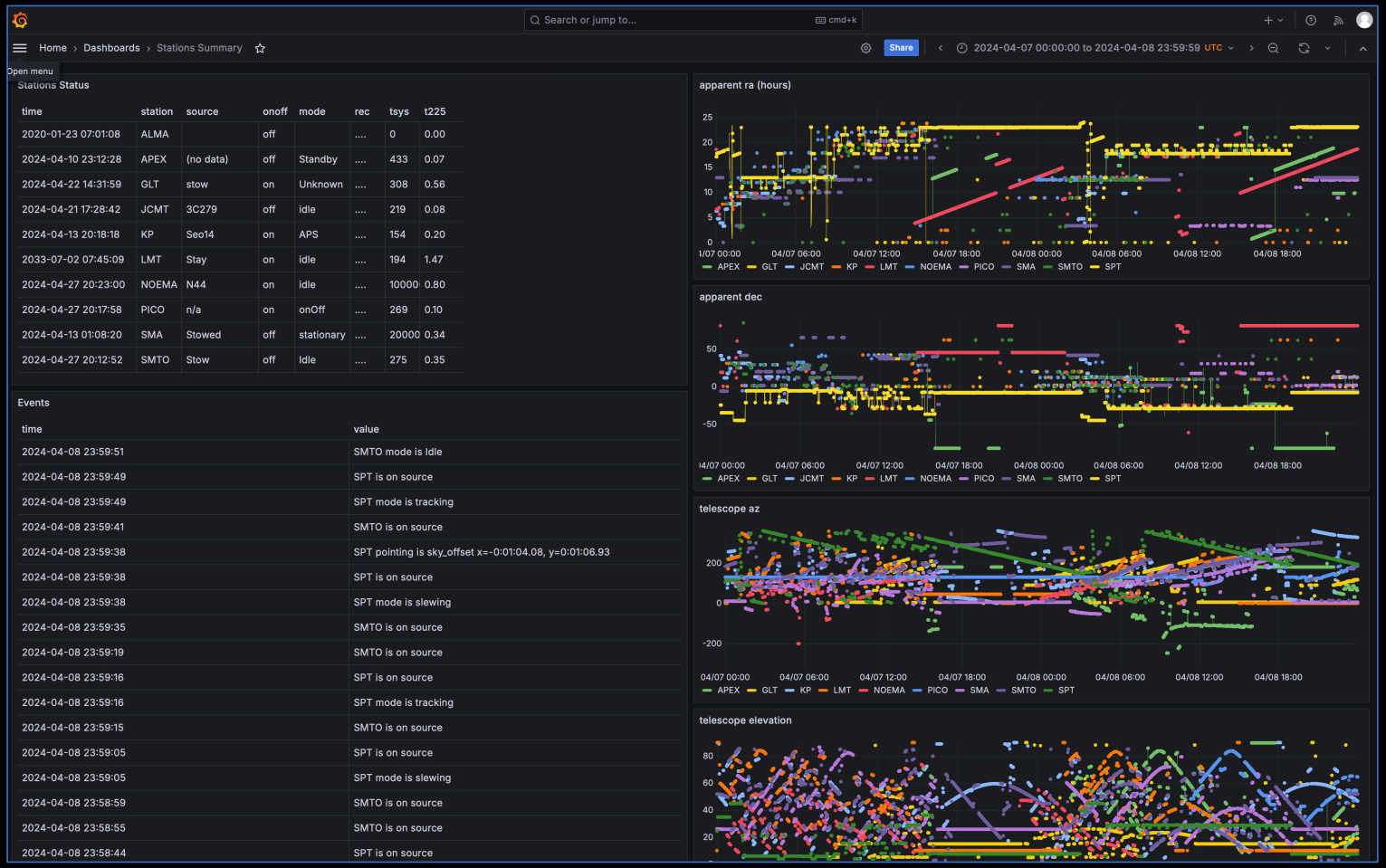
Real-Time Station monitoring:

- Stations are running VLBI monitoring scripts to push station statistics to a central Grafana server
- This central monitoring tool allows the AOC track in real-time during the campaign how the stations are operating

Remote access:

- Remote access to a station allows the Technical Operations Support to assist with troubleshooting the various subsystems during any critical system failures
- Remote operations can allow station staff to configure and operate remotely instead of being onsite which will save on staffing resources

EHT Network and Data Transport Activities



EHT Future, Challenges, and Improvements

Future EHT observation goals:

- Planning to increase from annually to monthly/weekly/snapshot observations
  - Allow ability to track targets like M87 to see short time changes and even create a movie!
  - Allow quick response/opportunistic targets
- Increase sensitivity and bandwidth which increases data recording volume

Challenges:

- The EHT is a large international collaboration with heterogenous array of station
  - Each station has its own unique challenges to support science goals
- Network/Data transport
  - Faster networks into Correlators for quicker fringe turn around *Haystack 100Gb/s upgrade ~~2023~~ 2024
  - Larger data storage at Correlators to handle the increased data volumes
  - Increase station network speed and reliability (last mile challenges)

Improvements:

- Network quantification
  - Running network tests from station to Correlator to determine bottlenecks
  - Implementation of network test nodes to add to station monitoring system
- Station setup procedures can be simplified and training of local staff paired with remote operations
- Reducing the unknowns

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Improving the EHT Data Network

The EHT is a collaboration of Radio Science Observatories around the world. We need to extend this collaboration to the Research Networks supporting the Science

How are we starting this?

- Engagement and Performance Operations Center (EPOC) @ Indiana University
- Internet2/ESnet
- The Correlator @ MIT Haystack Observatory (MIT)
- EHT Stations @ Mauna Kea (University of Hawaii)

Path Forward

- Quantify existing network infrastructure
- Deploy network test nodes (perfsonar) at EHT stations and Correlator to monitor performance
- Identify bottlenecks and develop an upgrade plan
- Demonstrate performance improvements with real EHT data

Future Plan

- Reach out to other Research Networks to expand the EHT Data Network

Summary

- The EHT campaigns will continue to rely on high-speed reliable Research Networks to support international operations
- Data transport on larger scales is the long term goal with many challenges along the way
  - Improving large high-speed networks out to remote stations but also to the Correlators
  - Optimizing these networks at an international level requires collaborations with the RENs
- On the short term – sending partial data back to Correlators for quick validation will continue to be important as we increase observation cadences
- Improving operations process and procedures for quicker turn-around
- Network quantification and station monitoring is a way to help track any changes in performance and help optimize data transport

Event Horizon Telescope

Thank you!

MIT HAYSTACK OBSERVATORY

NSF