# Haystack Observatory Post-processing System

Violet Pfeiffer as part of the HOPS team with John Barrett, Geoff Crew, and Dan Hoak







Event Horizon Telescope



#### What is VLBI?





#### Source: <u>https://en.wikipedia.org/wiki/File:The Southern Milky Way Above</u> <u>ALMA.ipg</u>

Source: <u>https://upload.wikimedia.org/wikipedia/commons/4/4a/</u> <u>Malargue-VLBI distances.png</u>



Source: <u>https://space-geodesy.nasa.gov/techniques/VLBI.html</u>

#### End Result -Graphs!





## Look at this graph



Source: https://www.youtube.com/watch?v=irDMI D18ek



#### What for?







Source:

<u>https://www.nasa.gov/image-article/sagittarius-nasa-telescopes-support-event-horizon-tpe-studying-milky-ways-black-hole/</u>



# Haystack Observatory Post-processing System (HOPS)

The software that allows this to happen!

First written in the 1970s by Alan Rogers in Fortran.

Programming languages:

Build tool:

- C/C++
- Python
- Nix
- Perl
- Fortran
- Shell

• cmake

Development environment:

• Ubuntu 22.04

Test environment:

- HOPS 3 (test oracle)
- Unit tests
- Regression testing



### Challenges

- Legacy code and Fortran
- Custom data types from the 70s
- Not all dependencies documented
- A lot of software assumes you are using X11 forwarding
- Astronomers like creating custom data types
- Resistance to change
- Disputes between using make and cmake
- Input data is anywhere between ~70-100+ GB
- Working with binary data
- I'm not a scientist!

#### NASA Goddard Geophysical and Astronomical Observatory (GGAO)



Website: <u>https://space-geodesy.nasa.gov/NSGN/sites/GGAO/site\_news/GGA</u> <u>O\_news.html</u>



### How do we get funding?







#### The elephant in the room...



Source: Dr. Joshua Weitz and team at UMD

#### Further reading

- Geodetic and Astrometic Measurements with very-long-baseline interferometry by Douglas Scott Robertson: <u>https://ntrs.nasa.gov/api/citations/19770025620/downloads/19770025620.pdf</u>
- Progress on the Haystack Observatory Postprocessing System by Dan Hoak, Violet Pfeiffer, John Barrett, and Geoff Crew: <u>https://www.mdpi.com/2075-4434/10/6/119</u>
- Nine years of monitoring the dependence of the GGAO12m phase calibration delay on antenna orientation by Violet Pfeiffer et al.: <u>https://www.haystack.mit.edu/wp-content/uploads/2024/06/VGOS 061.pdf</u>
- https://www.vlbi.at/data/publications/Nothnagel Elements of VLBI.pdf
- First Sagittarius A\* Event Horizon Telescope Results. I. The Shadow of the Supermassive
- Black Hole in the Center of the Milky Way the EHT collaboration et al: <u>https://iopscience.iop.org/article/10.3847/2041-8213/ac6674/pdf</u>
- Interferometry and Synthesis in Radio Astronomy by Thomson, Moran, and Swenson: <u>https://onlinelibrary.wiley.com/doi/book/10.1002/9783527617845</u>
- What is VLBI?: <u>https://space-geodesy.nasa.gov/techniques/VLBI.html</u>



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#### Github:

- <u>https://github.com/vpfeiffer</u>
- <u>https://github.mit.edu/violetp</u>

Website (coming soon): www.violetpfeiffer.com



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