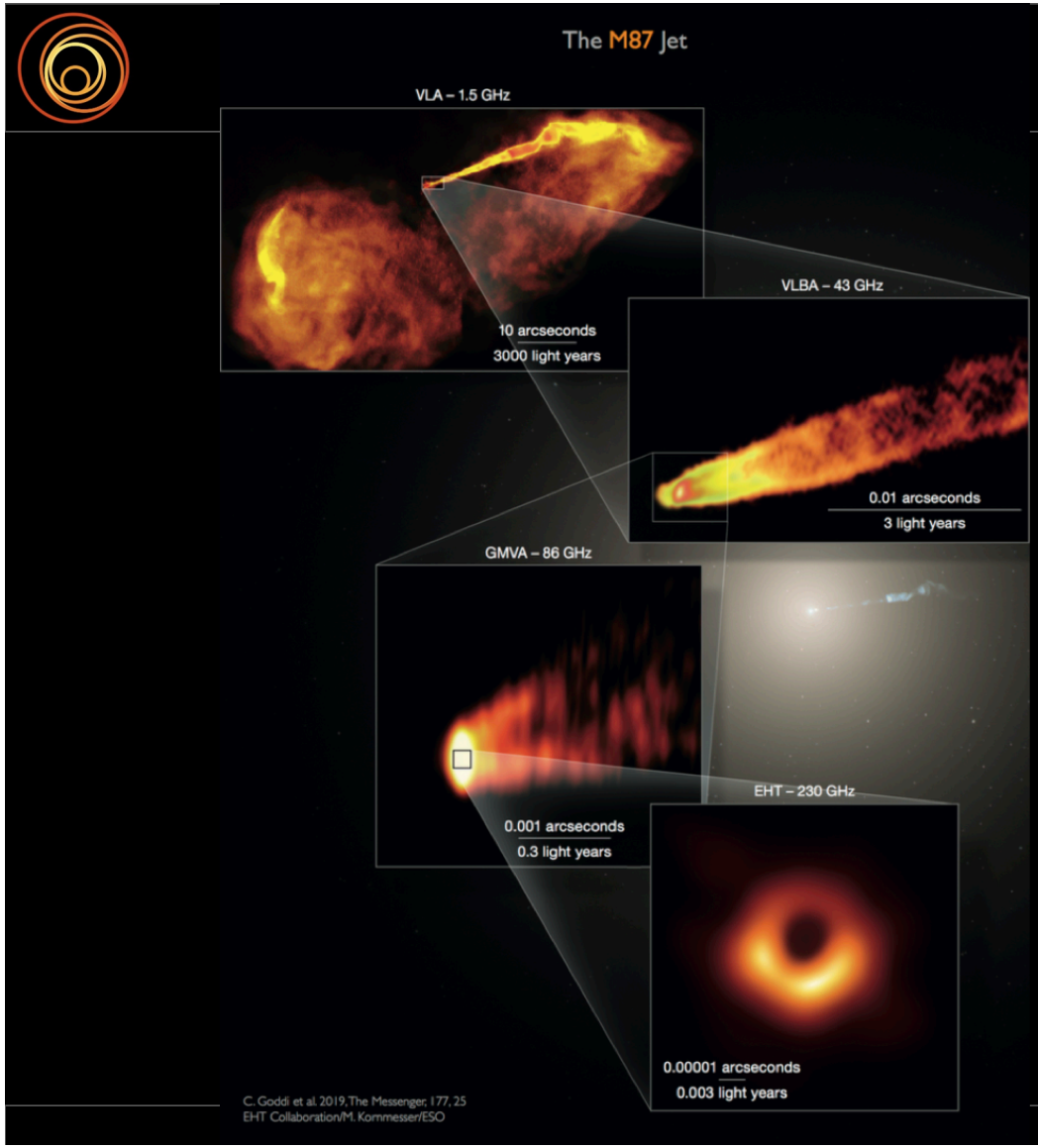
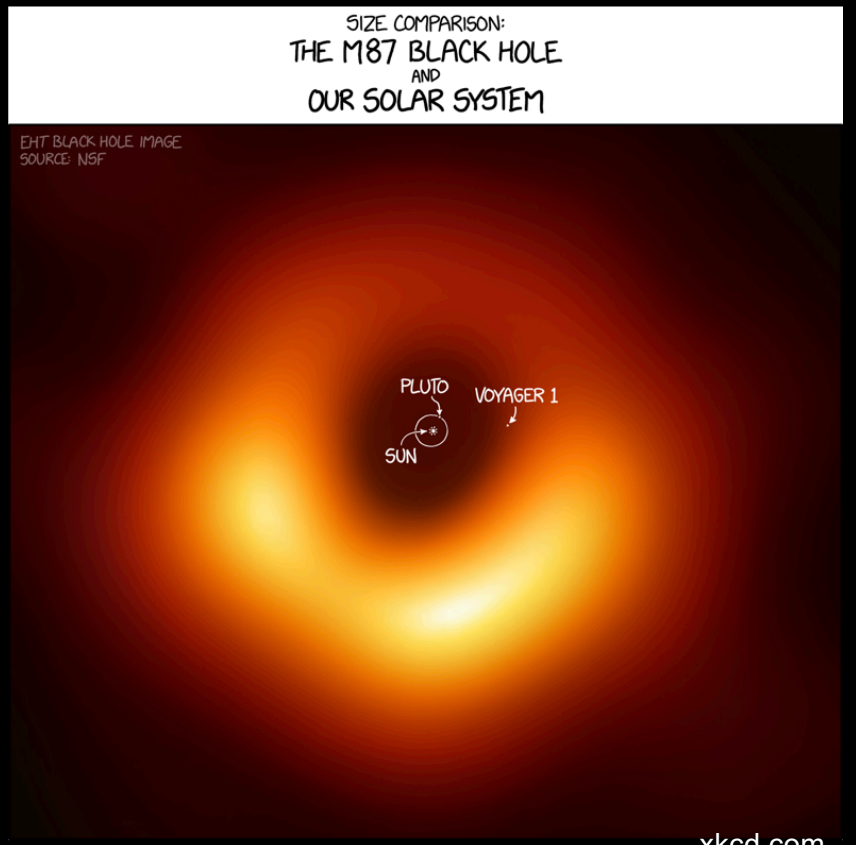
NEXT GENERATION EVENT HORIZON TELESCOPE

Kari Haworth, Chief Technology Officer
Center for Astrophysics | Harvard & Smithsonian

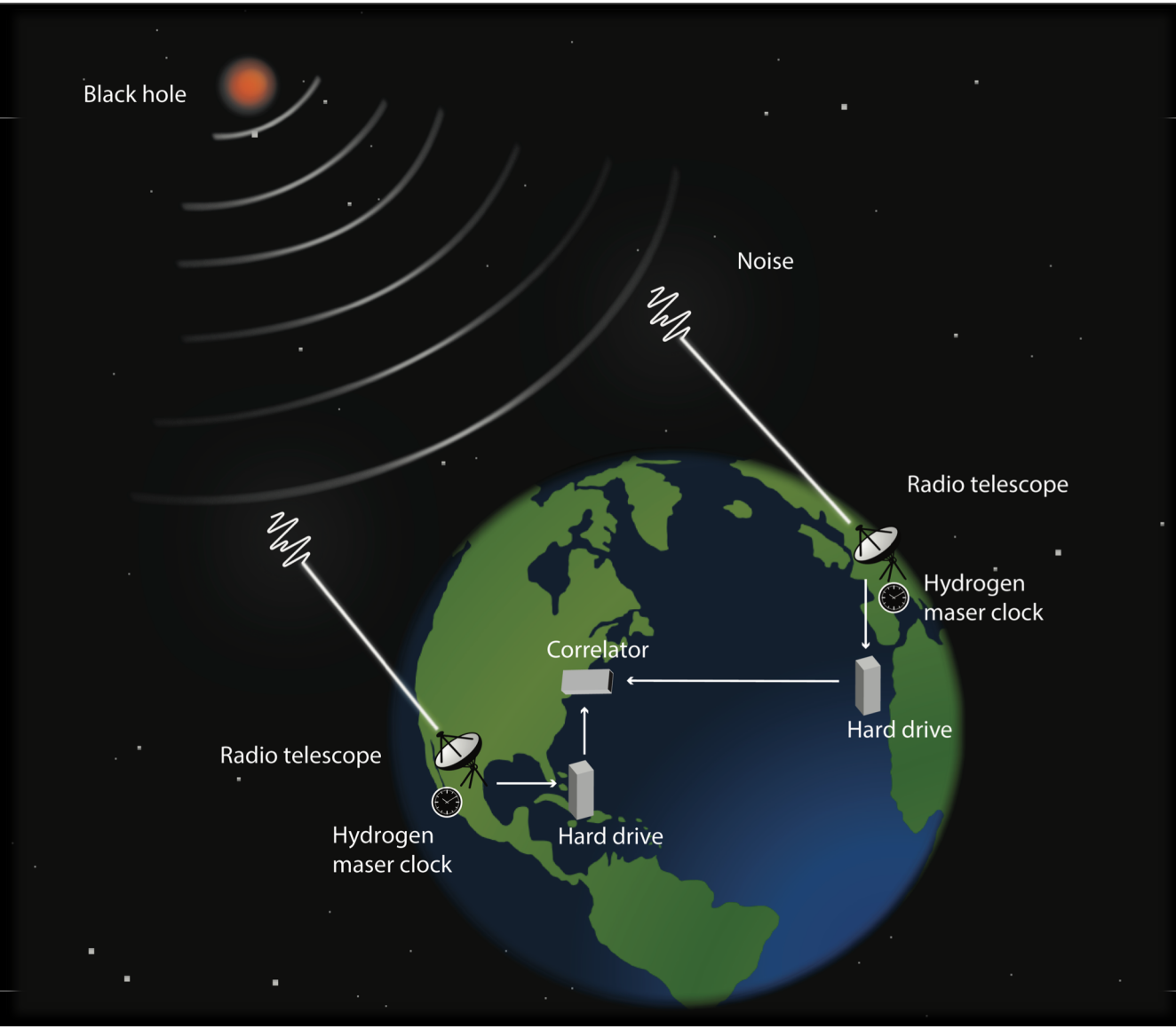
Shep Doeleman, PI // Michael Johnson, Project Scientist // Garret Fitzpatrick, Project Engineer
//Jonathon Schonfeld, Program Manager // ...and the growing ngEHT team

Tuesday, 13 April 2021 for South American Astronomy Coordination Committee


The M87 Jet
VLA – 1.5 GHz
10 arcseconds
3000 light years
VLBA – 43 GHz
0.01 arcseconds
3 light years
GMVA – 86 GHz
0.001 arcseconds
0.3 light years
EHT – 230 GHz
0.00001 arcseconds
0.003 light years
C. Goddi et al. 2019, The Messenger, 177, 25
EHT Collaboration/M. Kommesser/ESO

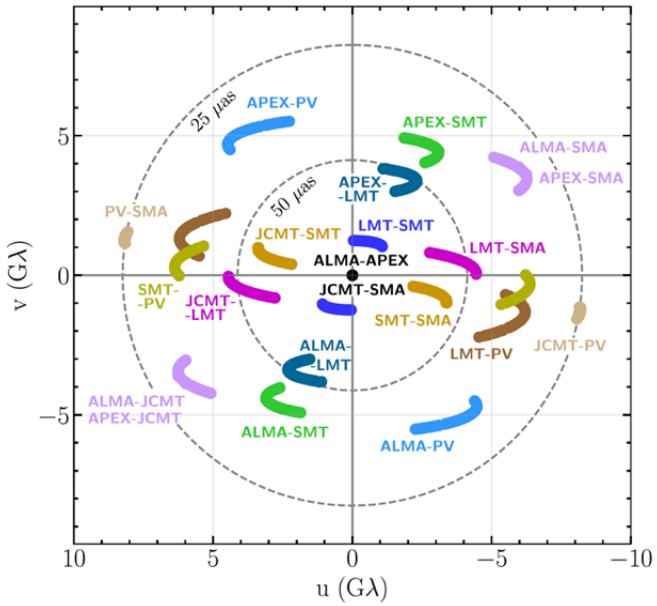

SIZE COMPARISON:
THE M87 BLACK HOLE
AND
OUR SOLAR SYSTEM
EHT BLACK HOLE IMAGE
SOURCE: NSF
PLUTO
VOYAGER 1
SUN
xkcd.com

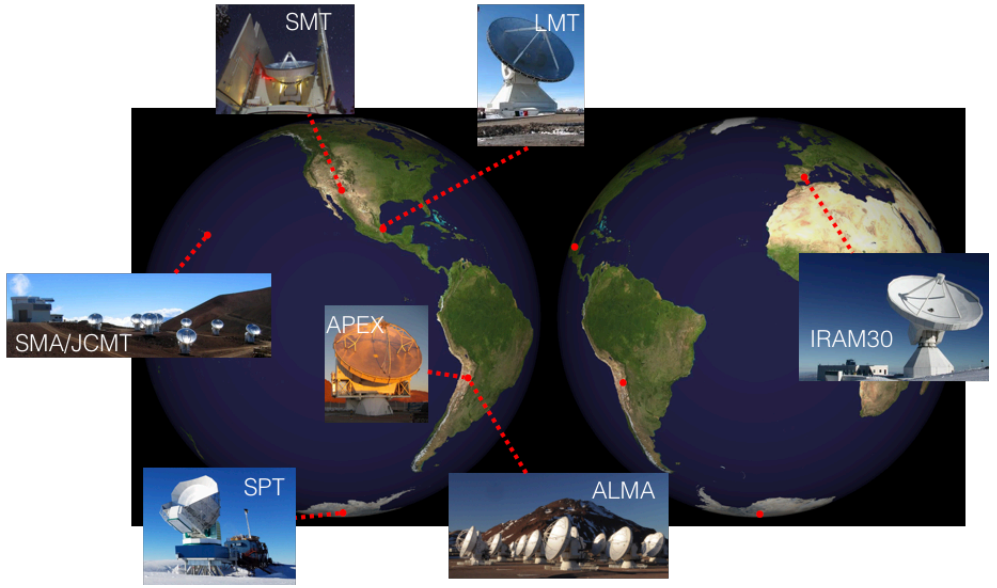
VLBI


Black hole
Noise
Radio telescope
Hydrogen
maser clock
Correlator
Hard drive
Radio telescope
Hydrogen
maser clock
Hard drive

First full EHT Observations: April 2017

- 8-Station EHT Array: APEX, SPT, ALMA, LMT, SMTO, JCMT, SMA, Pico Veleta.
- Dates: April 5-14, with 5 days 'triggered' on good weather.
- Weather: Fantastic.
- Successful: Detections to all 8 participating telescopes.





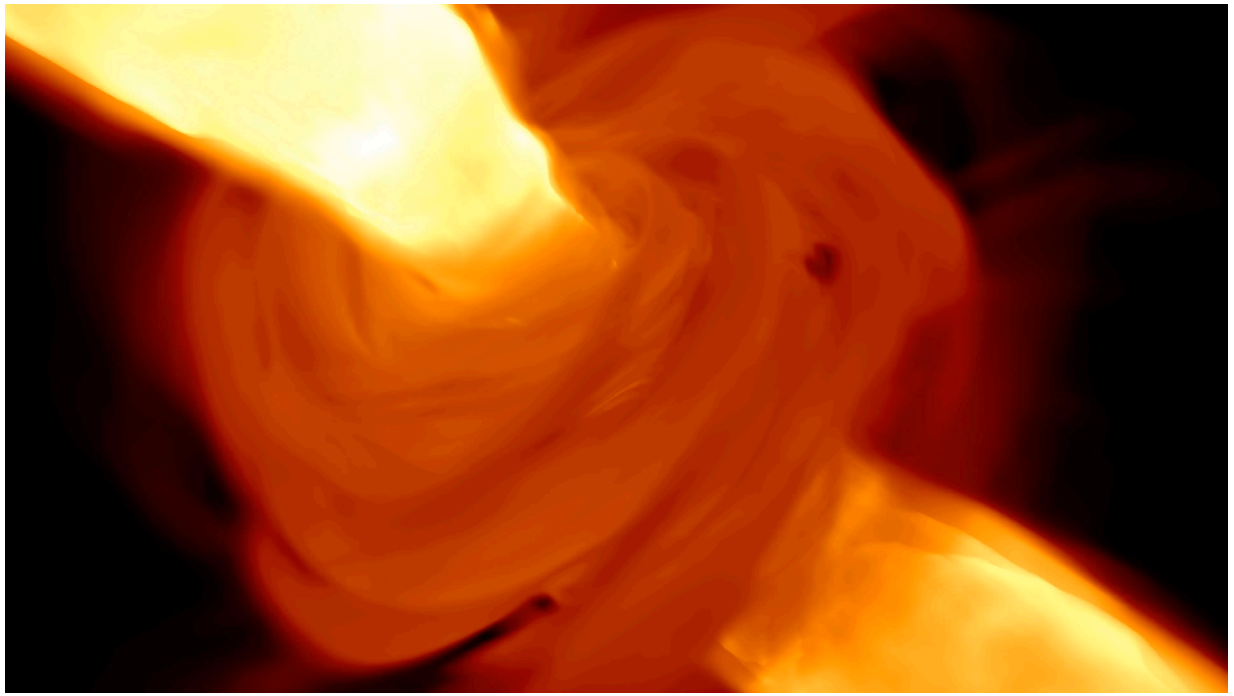
ngEHT: What's next?

New Science

- Testing GR to better precision
- Hybrid Imaging: fitting the n = 1 ring
- M87 jet accretion
- SgrA* time variability

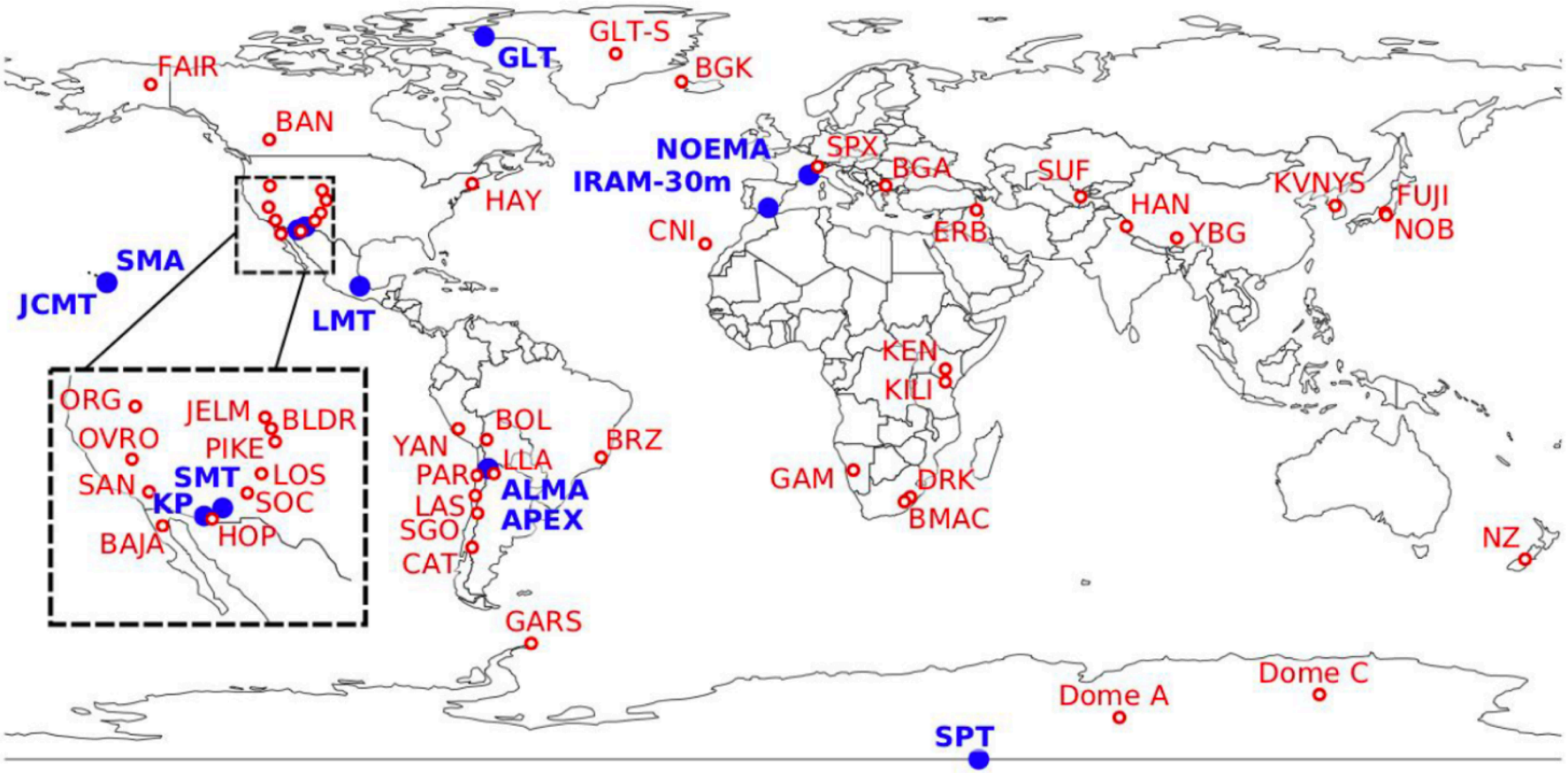
New technology

- Expanded sites
- Wider bandwidth
- Built-in autonomy
- Faster time-to-science



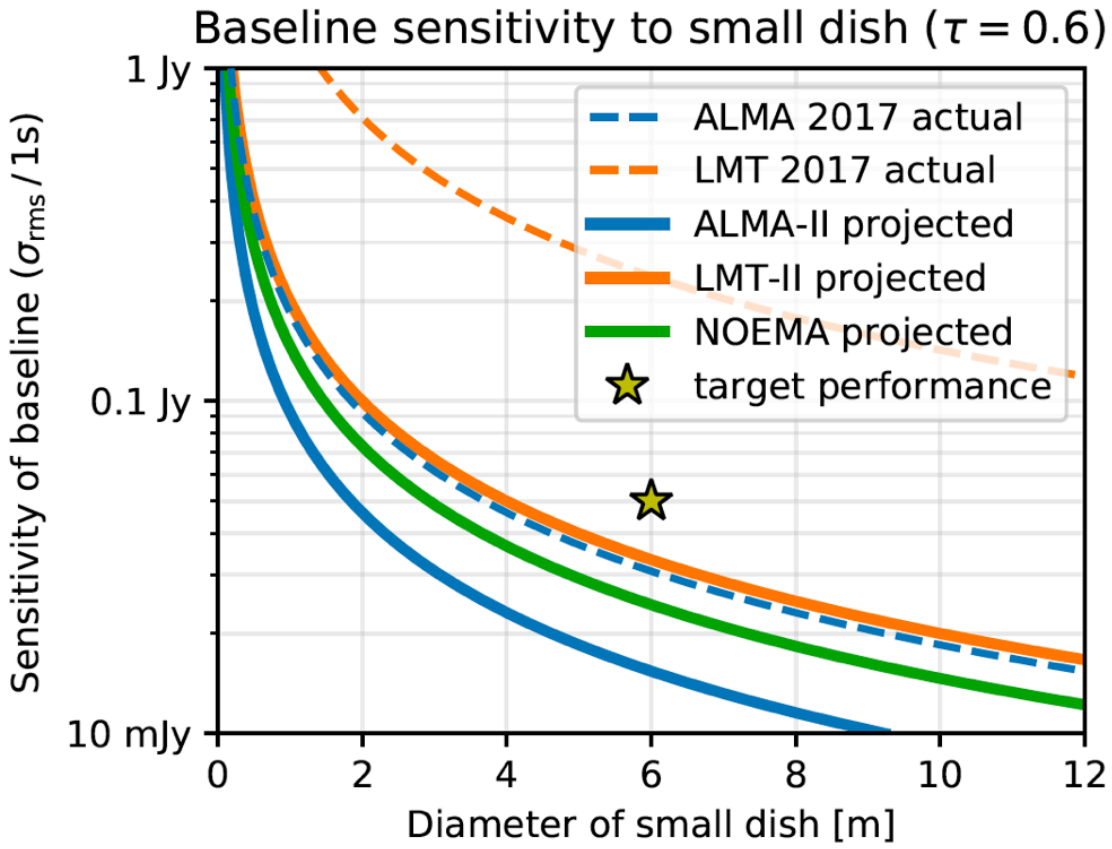
CK Chan et al, University of Arizona

ngEHT: Expanded sites



A. Raymond, D. Pesce, G. Lindahl, D. Palumbo, ngEHT team.

ngEHT Sensitivity and Expansion Concept: Small dishes can fill in Earth-sized aperture.



Anchor sites allow small dishes to add uv coverage.

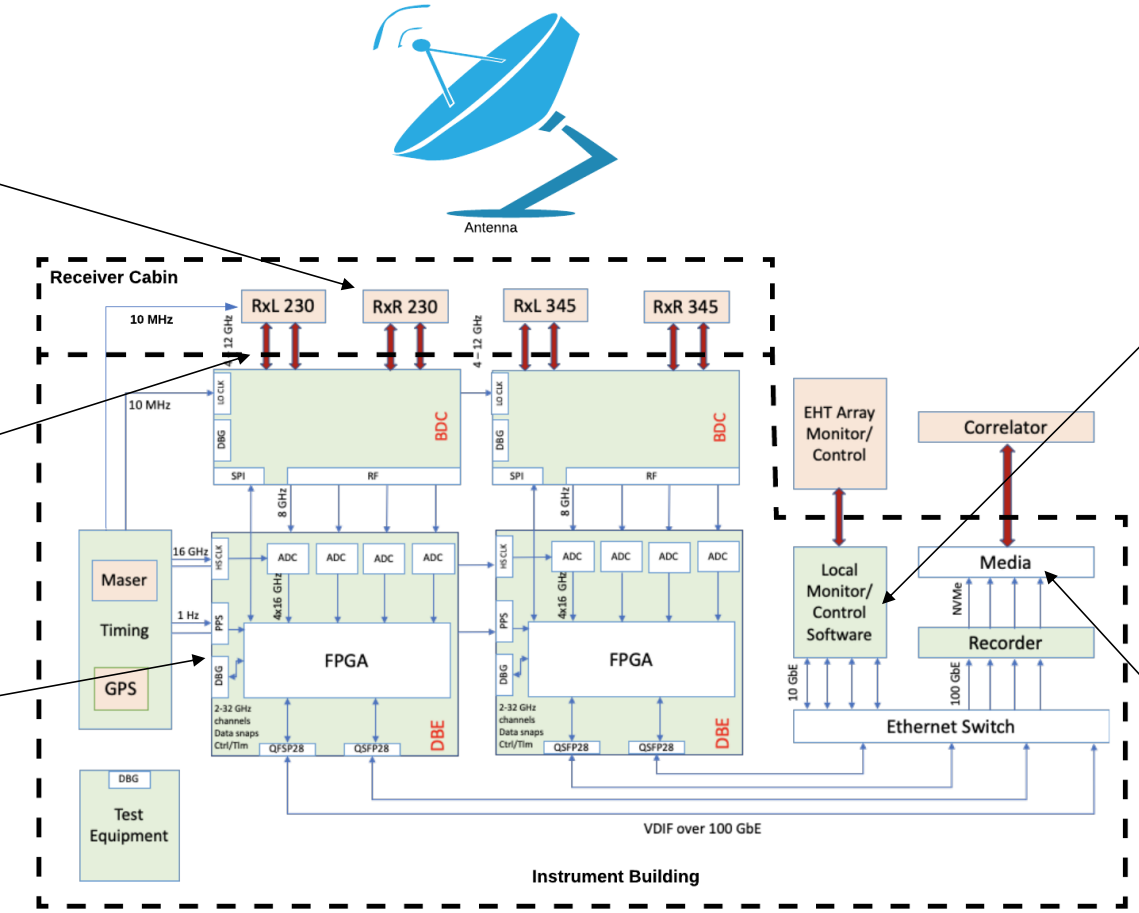
L. Blackburn

ngEHT Station Data Processing

Dual-band receivers for simultaneous 230/345 GHz observation

8 GHz bands, dual polarization, two sidebands gives a total of 64 GHz

4 16 GSps ADCs + high capacity FPGA processes 128 Gbps per board for a total of 256 Gbps



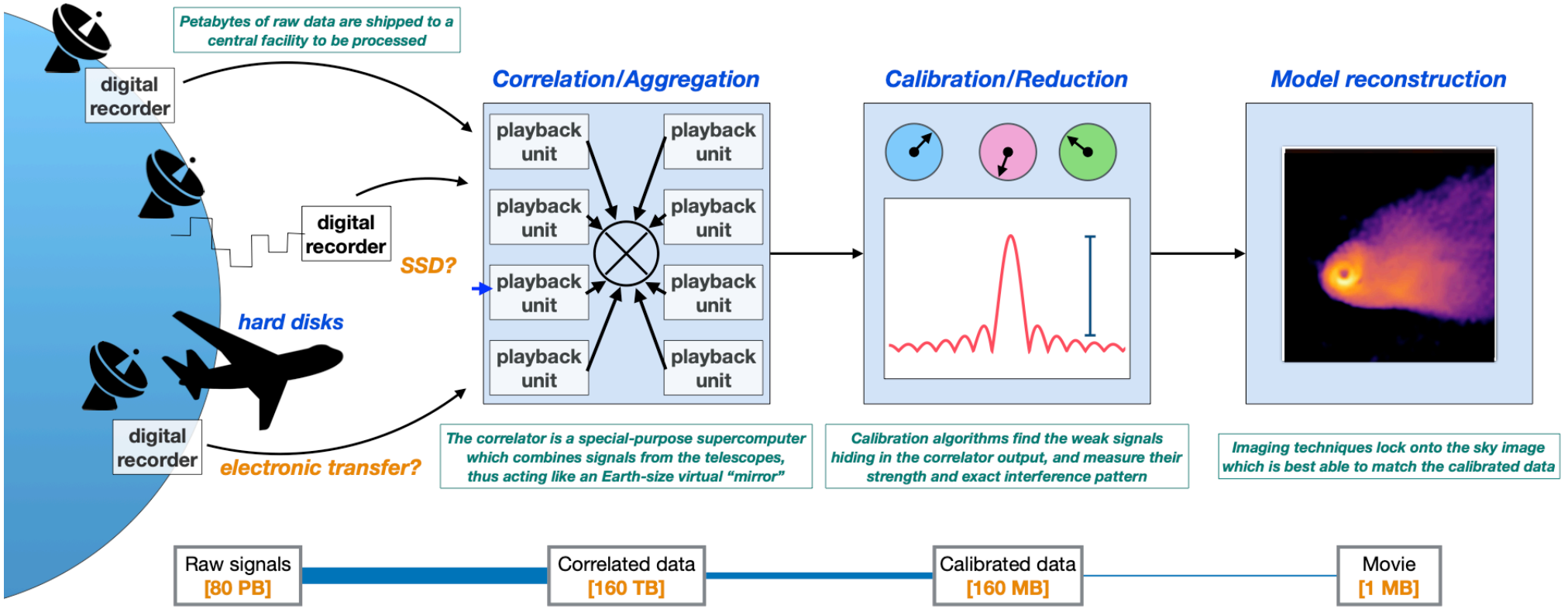
"Software first" gives a more robust remote control system for worldwide array

Fast data recorder takes advantage of COTS technology (1.7 PB/ 5-day campaign)

EHT/ngEHT Data Reduction

Signals arrive at the telescopes and are digitized and saved onto hundreds of hard disks

Petabytes of raw data are shipped to a central facility to be processed



The correlator is a special-purpose supercomputer which combines signals from the telescopes, thus acting like an Earth-size virtual "mirror"

Calibration algorithms find the weak signals hiding in the correlator output, and measure their strength and exact interference pattern

Imaging techniques lock onto the sky image which is best able to match the calibrated data

Raw signals [80 PB]	Correlated data [160 TB]	Calibrated data [160 MB]	Movie [1 MB]
sites x2 bandwidth x4	*baselines x4*	*dimensionality > x8*	*dynamical model high fidelity image*

12 orders of magnitude in data reduction!

Data transport/storage requirements and technologies

Unique simultaneous requirements lead to development of semi-custom equipment

- High bandwidth on-demand recording and playback (hot)
- Archival for months+ (cold)
- Portable (flexible transport)

EHT disk modules at MIT Haystack Observatory

However HDD speed and density increase at a slow pace look toward new enabling technologies

Commodity SSD storage

~few times cost of HDD (projected)

extremely high density and bandwidth

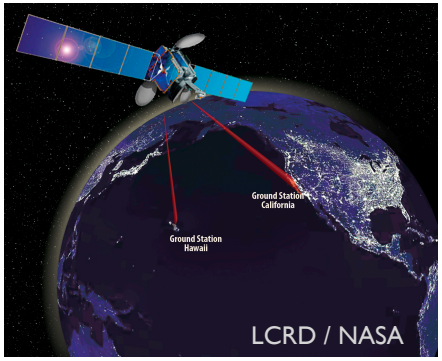
VLBI e-transfer of data

routinely done at lower rates / accessible sites

ground fiber - requires infrastructure

satellite RF (e.g. Starlink) ~1 Gbps

satellite free-space optical ~100 Gbps



Likely deploy new backend in staged approach, explore e-transfer in parallel

ngEHT Concept Development

Timeline:

- Phase I - design (2019-2024)
- Phase II - build out and commission (2024-2030)

New Stations: ~10 small aperture (6-10m) dishes at optimized locations.
Bandwidth Expansion: 256 Gb/s (x4)
Dual Band Observing: 1.3mm/0.87mm
Data Volumes: 10-100 PBytes
High speed data capture and transport: leveraging COTS systems.
Data Processing: x16 computational load
Cloud correlation: shifting all processing to a massively parallel platform.
Optimizing Algorithms: Multi-frequency Synthesis, Dynamical Imaging, …

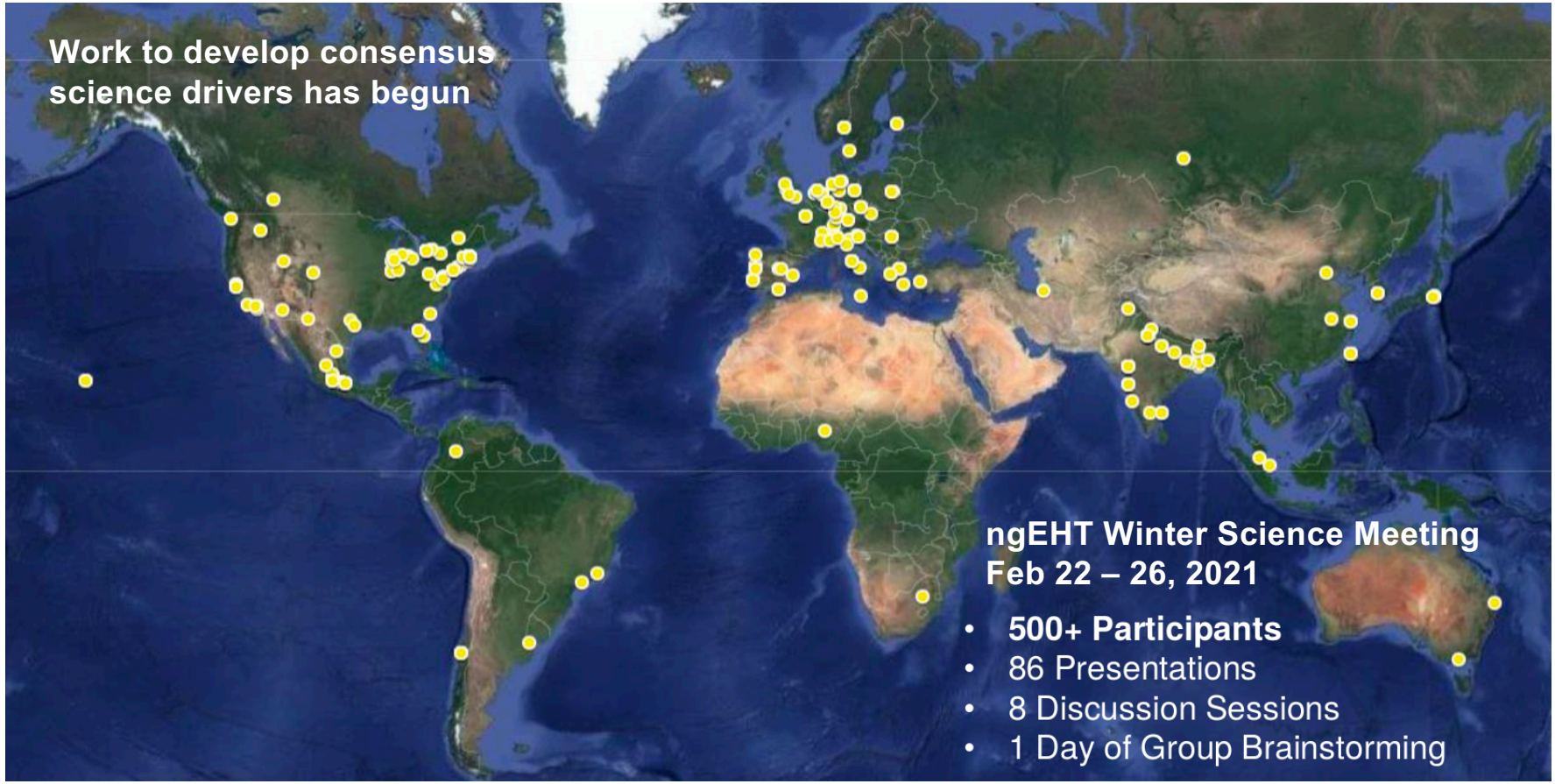
Astro2020 APC White Paper

Studying Black Holes on Horizon Scales with VLBI Ground Arrays

Lindy Blackburn[1,2,*] Sheperd Doeleman[1,2,*], Jason Dexter[12], José L. Gómez[16], Michael D. Johnson[1,2], Daniel C. Palumbo[1,2], Jonathan Weintroub[1,2], Joseph R. Farah[1,2,21], Vincent Fish[4], Laurent Loinard[18,19], Colin Lonsdale[4], Gopal Narayanan[28], Nimesh A. Patel[2], Dominic W. Pesce[1,2], Alexander Raymond[1,2], Remo Tilanus[17,22,23], Maciek Wielgus[1,2], Kazunori Akiyama[1,3,4,5], Geoffrey Bower[6], Avery Broderick[7,8,9], Roger Deane[10,11], Christian Michael Fromm[13], Charles Gammie[14,15], Roman Gold[13], Michael Janssen[17], Tomohisa Kawashima[4], Thomas Krichbaum[29], Daniel P. Marrone[20], Lynn D. Matthews[4], Yosuke Mizuno[13], Luciano Rezzolla[13], Freek Roelofs[17], Eduardo Ros[29], Tuomas K. Savolainen[29,30,31], Feng Yuan[24,25,26], Guangyao Zhao[27]

Estimated Cost:
Construction $140M
Operation $13M/year

Ideas drive design



Summary

- International work on ngEHT design is underway.
- Visionary: we will produce the first black hole movies - looking for ‘executive producers’!
- Committed to an inclusive program with leadership development and opportunities for early-career researchers.
- Target of late 2024 for final design and proposals for construction - completion by 2030.
- Anticipate 50% of construction costs from non-US international contributions (similar to EHT).