EVENT HORIZON TELESCOPE

An Earth-sized telescope to take the first image of a black-hole

CENTER FOR ASTROPHYSICS | HARVARD & SMITHSONIAN

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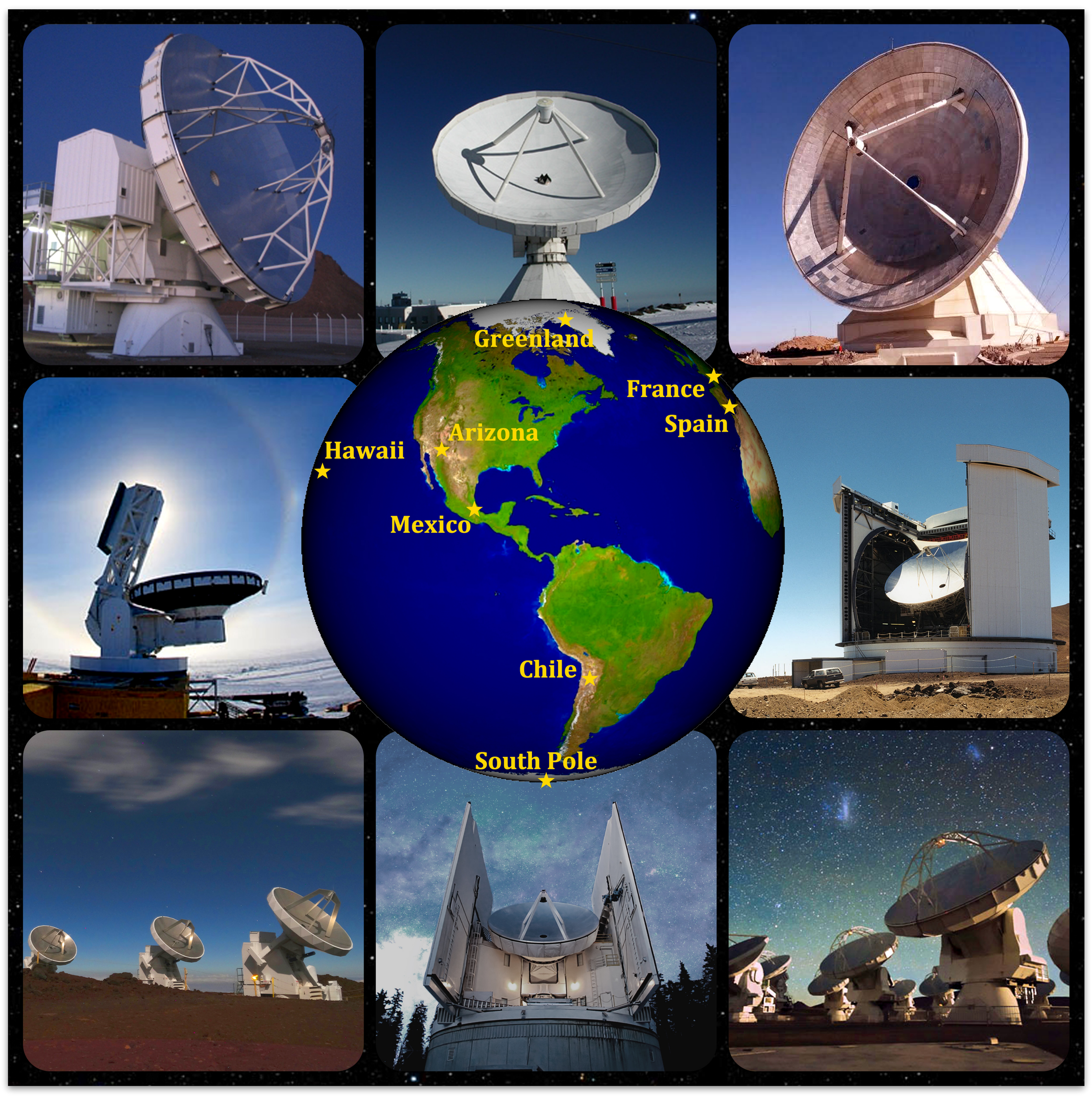
The Event Horizon Telescope

The Event Horizon Telescope (EHT) is a global 1.3-mm VLBI array achieving angular resolutions of tens of *micro*-arcseconds — sufficient to resolve horizon-scale features for nearby supermassive black holes (SMBH). EHT results to date include,

- Discovery of ordered magnetic fields near the horizon of Sgr A*
- Non-Gaussian structure in Sgr A* with persistent asymmetry
- Observation of time-variable polarized structure in Sgr A*
- Limits on M87 spin from jet base morphology

The Sub-millimeter Array (SMA) on Mauna Kea, Hawaii provides the majority of East-West coverage for the EHT. As one of the initial sites, SMA was central to early groundbreaking results which relied on the sensitivity of the SMA phased array, and the accurate amplitude and polarization calibration provided by the connected-element interferometer operating in coincidence with VLBI.

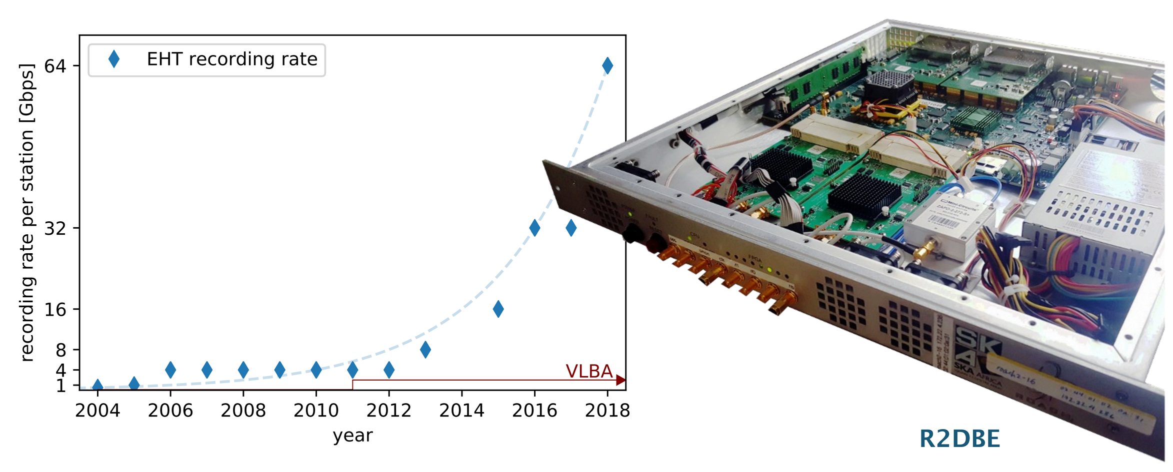


The EHT has undergone rapid upgrades over the course of the last few years, reaching a 9-station configuration and nominal design goal of 64 Gbps per site in 2018. The greatly increased sensitivity, baseline length and coverage will provide the EHT the capability for:

- Imaging the black hole shadow and inferred magnetic fields in the immediate vicinity of the SMBH at Sgr A* and at the center of M87
- Spatially resolving dynamical behavior at Sgr A* on the time scale of minutes (ISCO = 4-30m depending on spin)
- sub-pc resolution images of bright radio targets (3C273, OJ287, …)

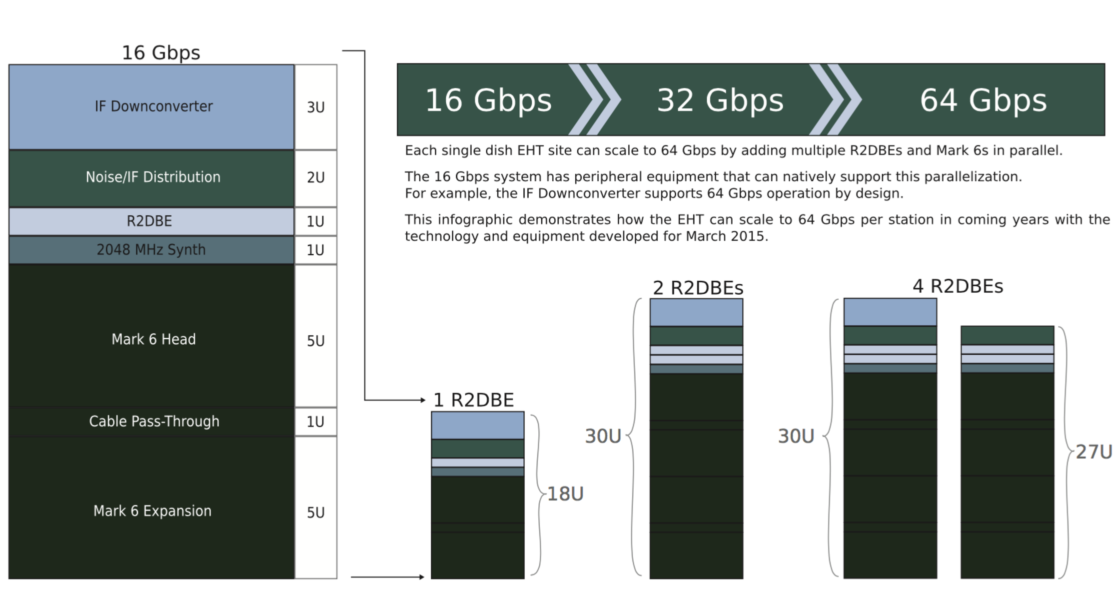
Ultra high-bandwidth VLBI

The EHT has pushed the boundary of high-bandwidth VLBI by continued development in the integration of state-of-the-art digital samplers, new digital backends, and high-speed recorders.



As of 2018, the bandwidth recorded at all EHT stations (8 GHz, dual-polarization = 64 Gbps) is over 30x the rate of the VLBA, providing sufficient sensitivity to detect sources on the longest EHT baselines and conduct precision measurement on short timescales.

By leveraging commercial off-the-shelf hardware and open-source hardware and software, the EHT has kept pace with Moore's law through >10 years of development. A single EHT observation records in total several PB of raw data over the course of a few nights, onto banks of 6-10TB He-filled hard disks.

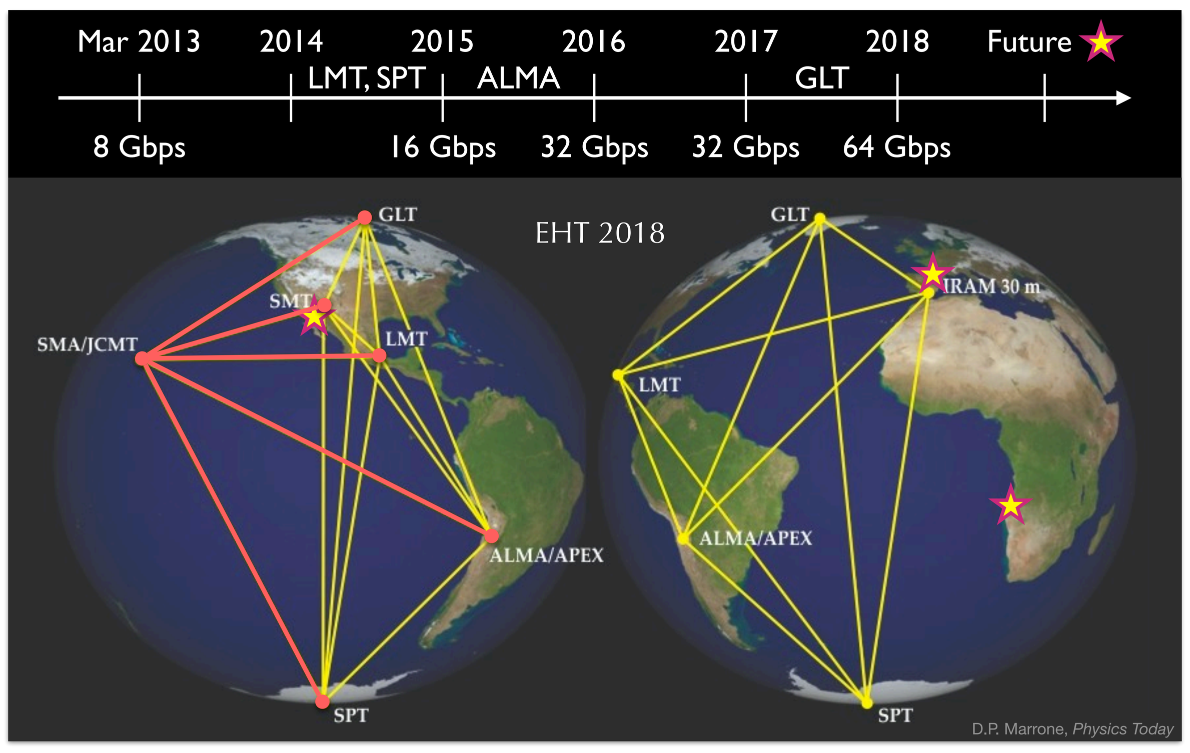


[L Vertatschitsch et al, 2015]

Building the EHT

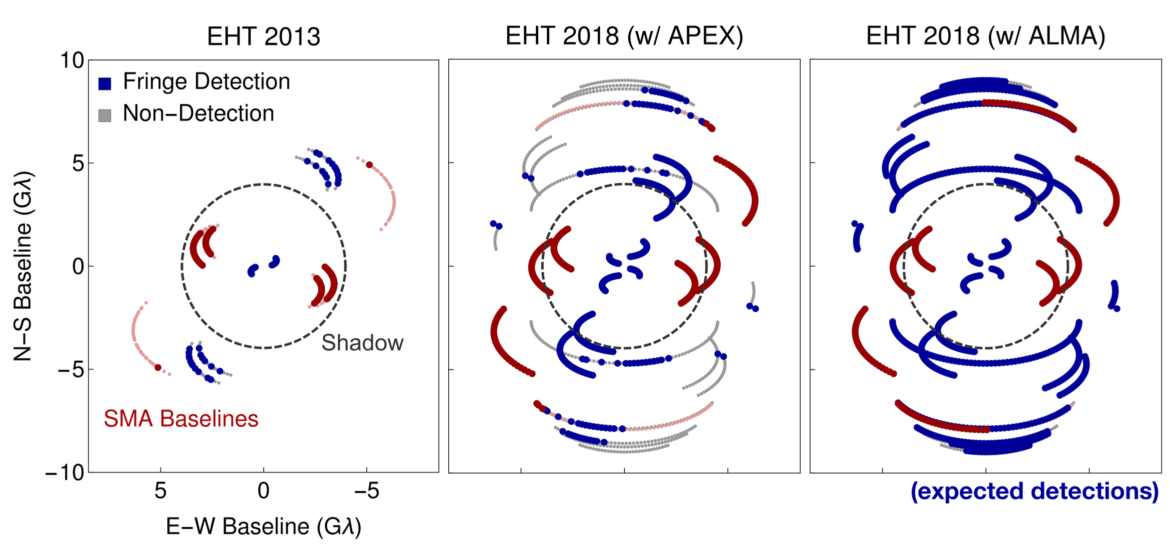
The EHT has steadily deployed new equipment to existing mm radio facilities to enable 1mm VLBI. In Spring 2017, the EHT observed with 8 stations including the SMA and ALMA phased arrays, and SPT, with fringes (correlated signals between sites) seen to all sites. In 2018, the EHT added the GLT (Greenland Telescope) and reached its design specification of 64 Gbps (8 GHz dual-polarization).

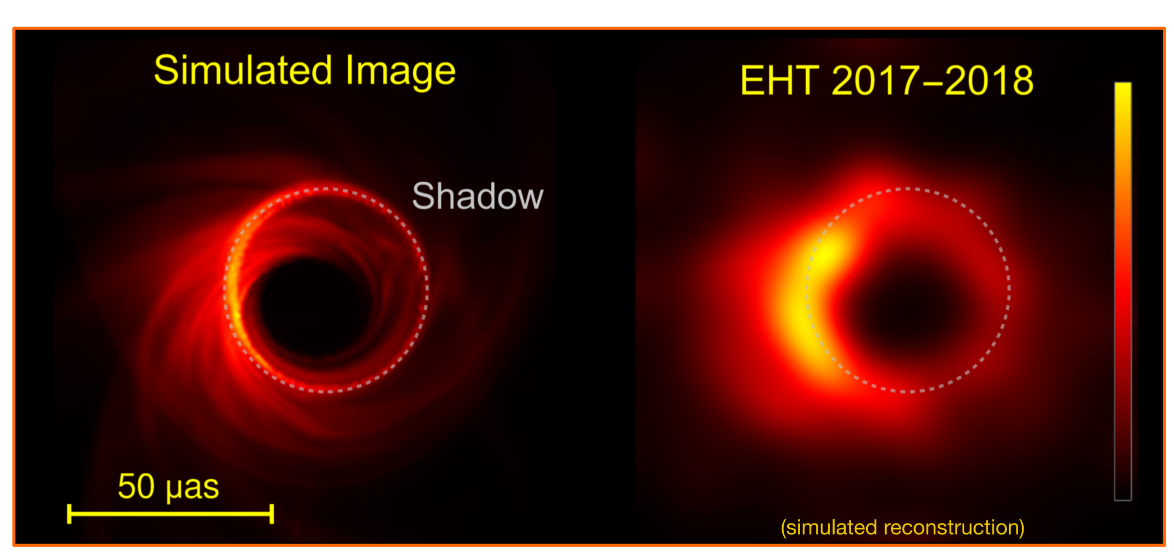
- 2013: 1 GHz BW, dual polarization, CARMA/SMA/SMT/APEX
- 2015: 2 GHz BW, dual polarization, +LMT (32m diameter)
- 2016: 4 GHz BW, dual polarization, +ALMA phased array test
- 2017: 4 GHz BW, dual polarization (32 Gbps), +SPT
- 2018: 8 GHz BW, dual polarization (64 Gbps), +GLT, +LMT (50m)



The SMA/JCMT pair provides the EHT with crucial East-West coverage, with confident amplitude calibration through the two-site redundancy. The SMA also ensures that EHT observations always have simultaneous coverage with a connected-element interferometer, which is especially important when observing Sgr A* as the source varies on short timescales.

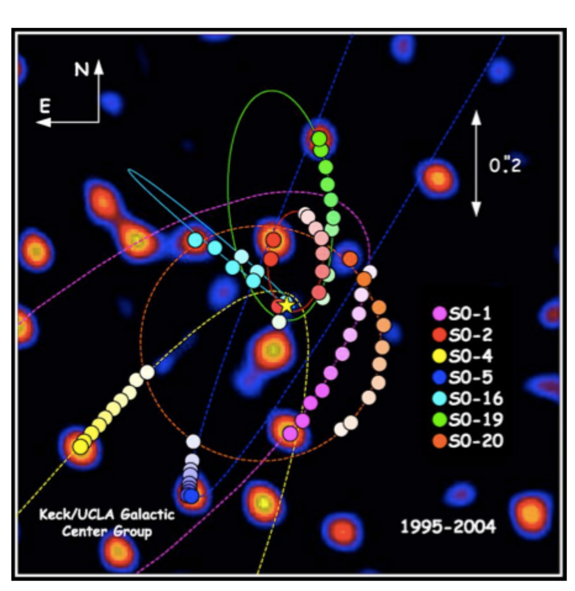
The ALMA phased array (37+ ALMA antennas acting as a large single dish) provides the necessary sensitivity to connect long baselines in the global array by locking in the relative timing and atmospheric phase variations between EHT sites, particularly for the South-Pole Telescope. The resulting full coverage allows imaging at event-horizon scales.





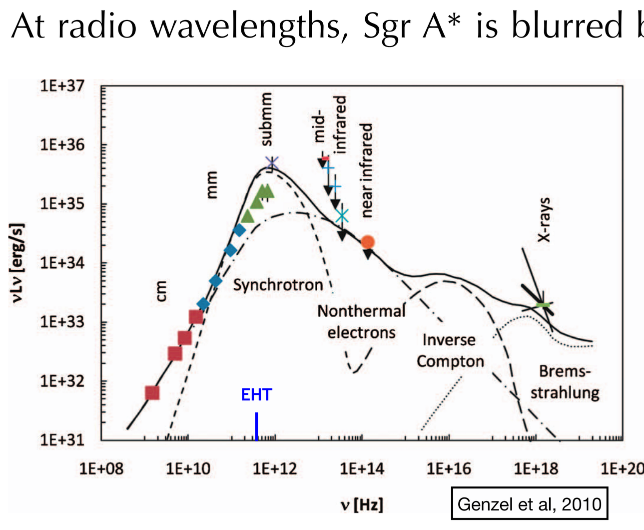
Sgr A* at the center of the Milky Way

Sgr A* is the supermassive black hole (4×10^6 M_{sun}) at the Galactic Center and has the largest apparent size on the sky (50 micro-arcsec shadow) of known black-holes. For AGN, it is under-luminous (9 orders of magnitude under Eddington) with spectrum that peaks in the sub-mm.



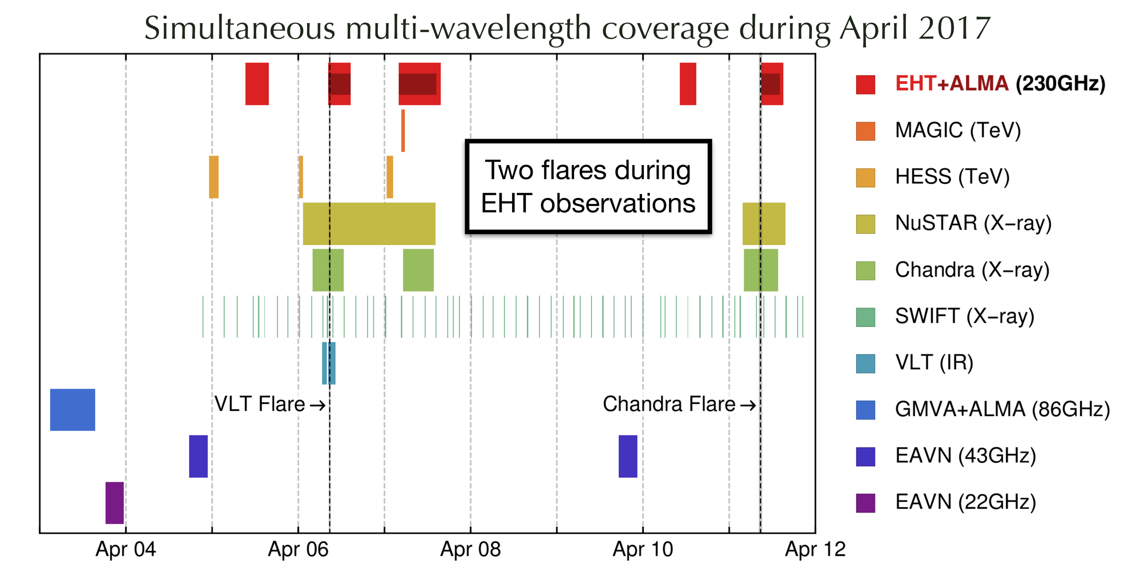
Dynamics of S0 stars provide strong evidence of black-hole, with closest approach ~45 AU. EHT resolution is ~0.15 AU.

At radio wavelengths, Sgr A* is blurred by strong interstellar scattering; an effect that scales as λ^2. At 1.3mm, the intrinsic shape of Sgr A* can be resolved, with a characteristic size of ~37 micro-arcsec first measured using an early EHT sub-array (Doeleman et al, 2008). At 1.3mm and below, the accretion disk also becomes optically thin, allowing emission from near the event horizon to be seen.

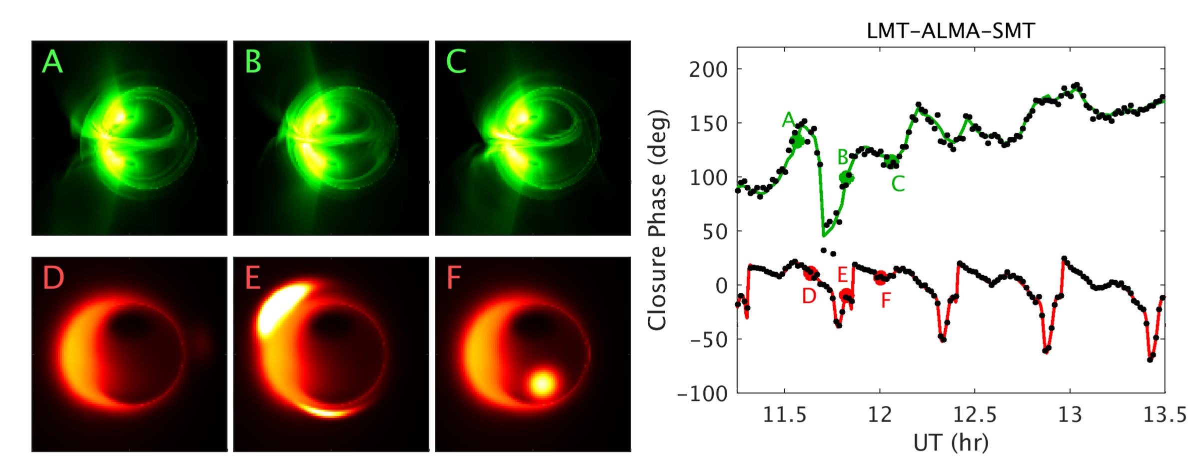


Spatially-resolved dynamics of Sgr A*

Sgr A* is known to flare in NIR and X-rays lasting ~minutes, corresponding to only a few R_{Sch} light-crossing timescales. The EHT will spatially resolve and track the evolution of these events for the first time through coordinated multi-wavelength observations from radio to γ-rays.



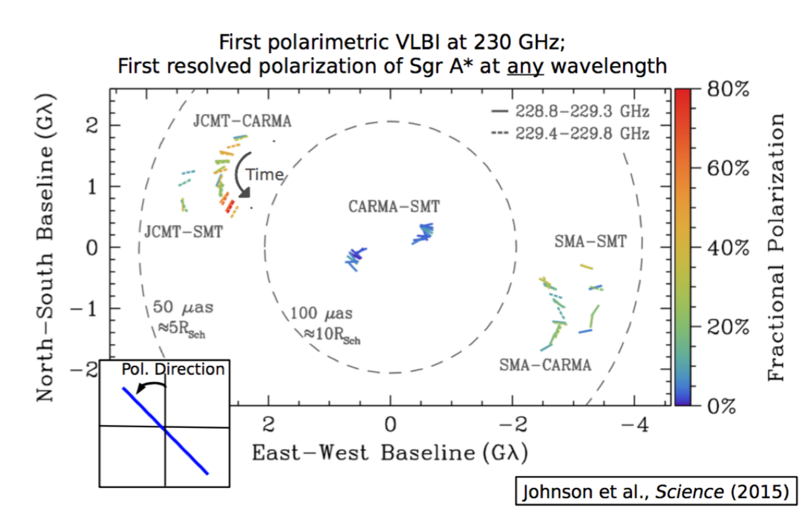
Dynamical models from GRMHD turbulence (green, Gold et al 2016) or a semi-analytic rotating hot-spot model (red, Broderick and Loeb 2006) produce high-SNR phase variations between EHT sites.



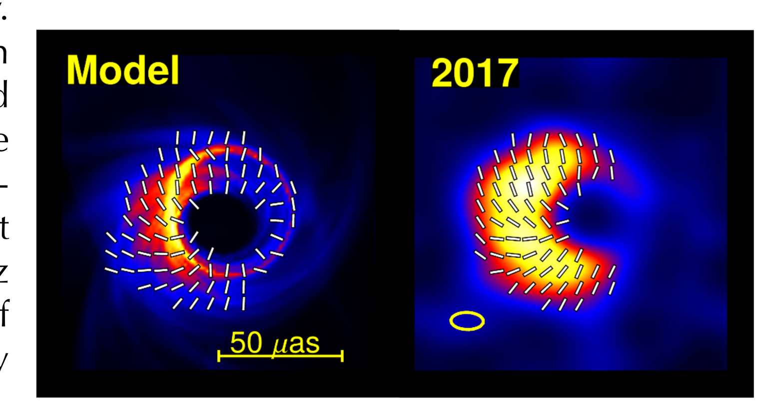
For a turbulent accretion disk, the spectrum of time variability in either closure phase or polarization fraction encodes information about the characteristic size of density fluctuations. The periodic signal of the hot-spot represents its orbital timescale, which tells us how close it is to the black hole and places constraints on black-hole spin.

Magnetic field structure at the horizon

The EHT upgraded to dual-polarization in 2013, with precise polarization calibration facilitated by the inclusion of the SMA phased array. This upgrade led to the discovery of ordered magnetic fields near the event horizon of Sgr A* through the linear polarization and smoothy-varying (~70%) on long EHT baselines between Hawaii and California/Arizona. The degree of polarization observed is consistent with synchrotron emission from GRMHD model simulations.



Full linear polarimetric imaging at horizon scales is achievable with the EHT 2017 and 2018 array. The polarization direction traces the magnetic field orientation and spacetime geometry, and future multi-frequency observation at both 230 and 345 GHz may provide estimates of field strength by spatially resolving rotation measure.



[A. Chael et al, 2016]

EHT Collaboration

EHT Collaboration Meeting Nov 2016, Cambridge, MA

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SMA Advisory Council Meeting, Cambridge, MA, July 17, 2018