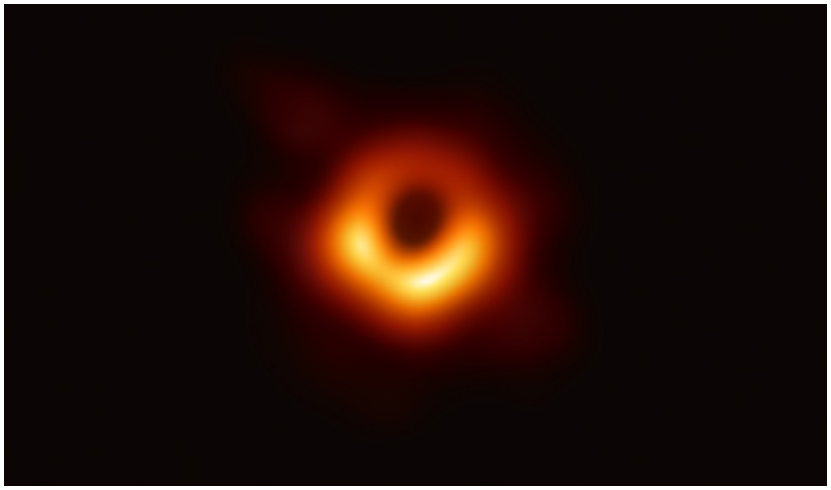
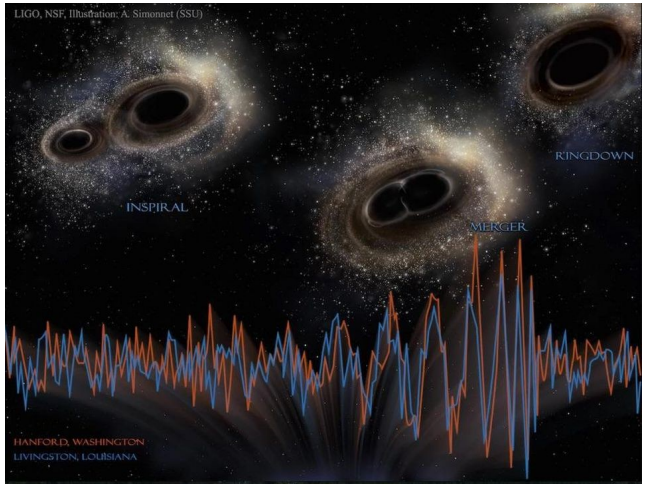
Event Horizon Telescope and LIGO Gravitational Waves---News



Bill Gabella

Monday 24 June 2019

Vanderbilt-QuarkNet Workshop



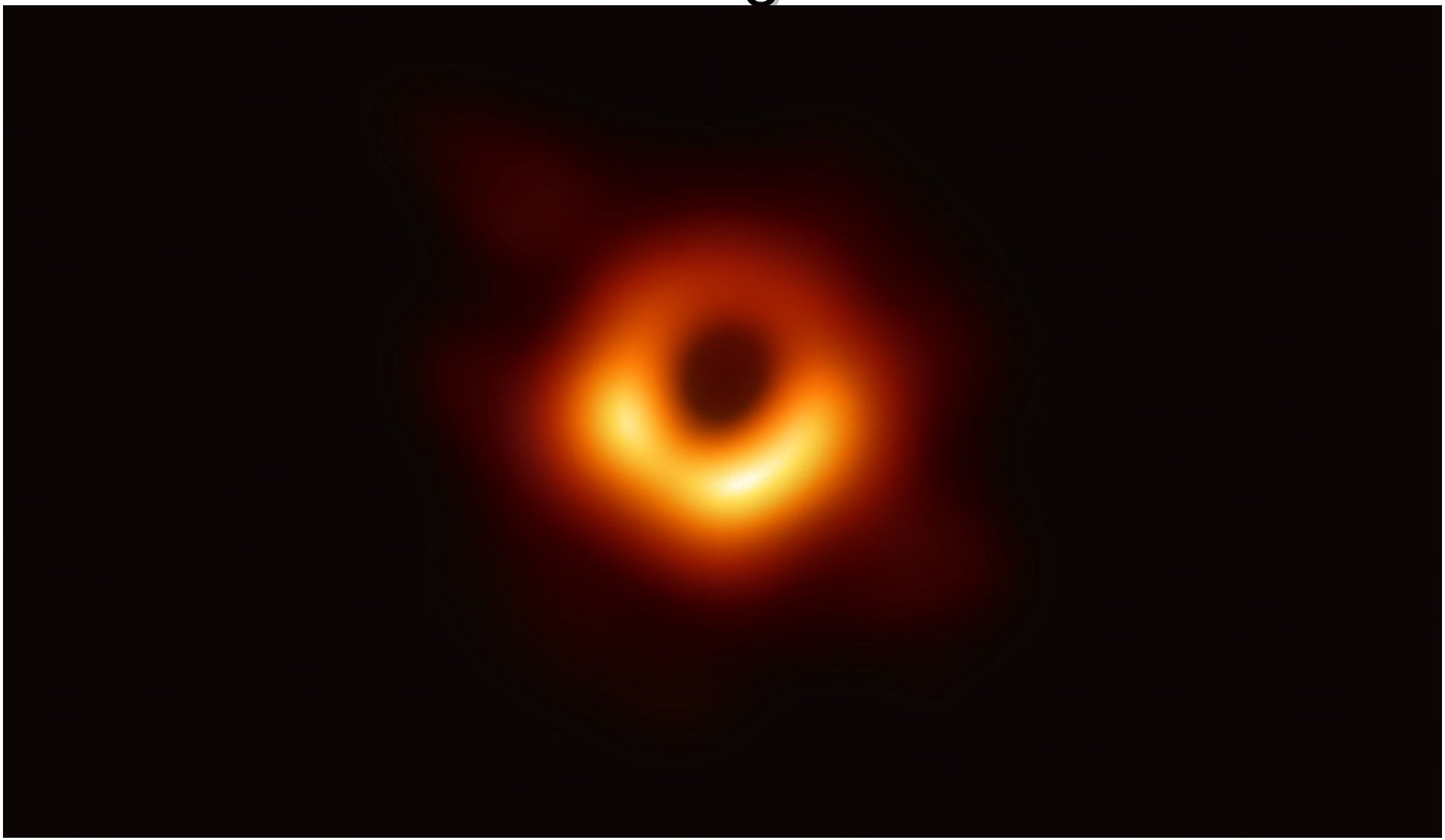
Ref: https://eventhorizontelescope.org/

Ref: https://gracedb.ligo.org/

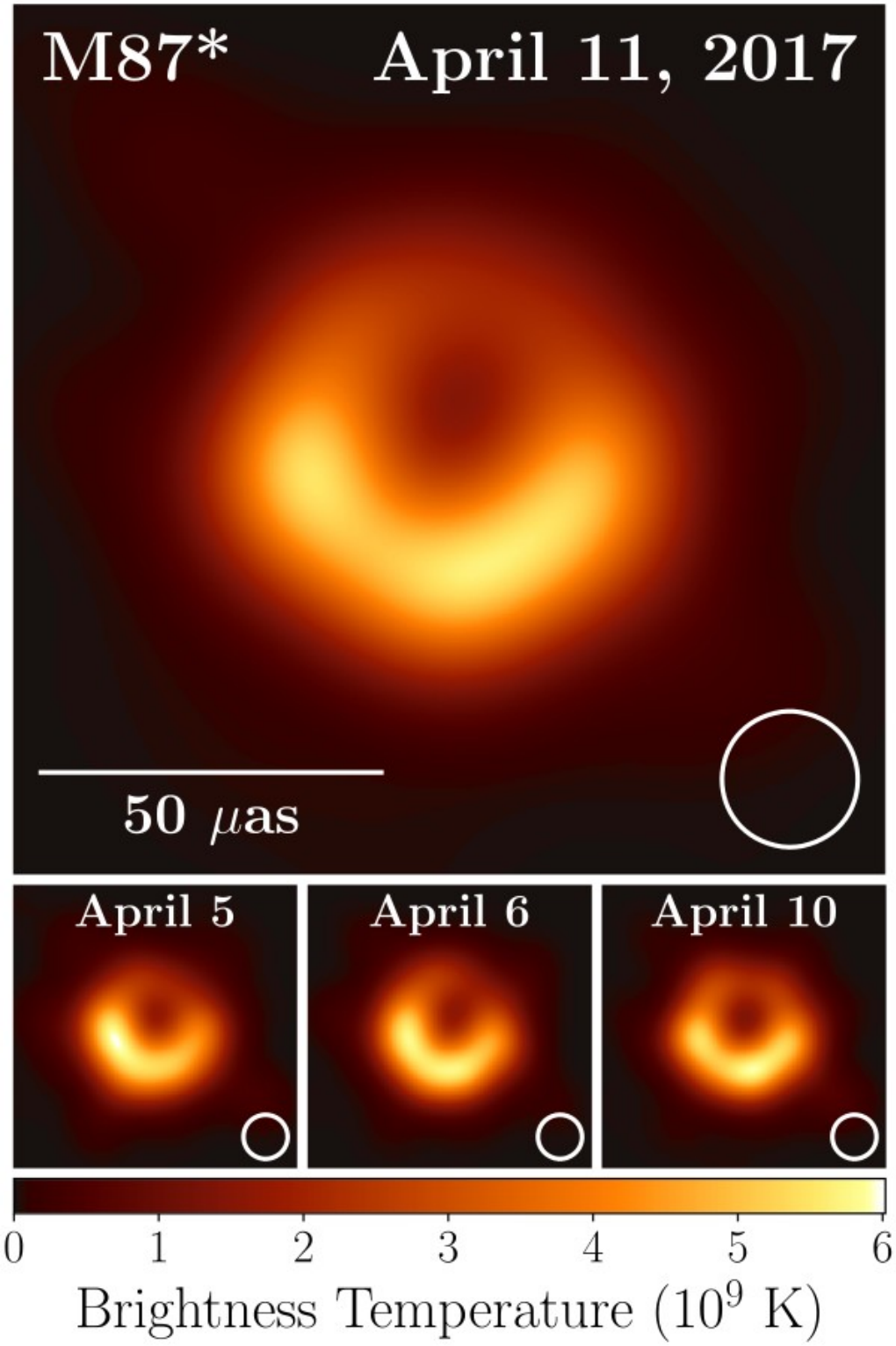
Event Horizon Telescope (EHT)---the Announcement

- Announced on 10 April 2019 for image of M87* (the supermassive black hole at the center of the galaxy M87).
  - Press Conference https://youtu.be/lnJi0Jy692w
- Data taken April 2017 and stored on hard drives from 8 radio telescopes around one hemisphere of the Earth.
- Imaged the light (radio waves) emitted around the SMBH M87* as it reached us. Shows a “shadow” characteristic of, and related to, the size of the event horizon of the black hole.
- Also they have data for Sgr A*, the SMBH in the Milky Way. For which they do not have image reconstructions yet.
- Routinely imaged a well known quasar, aka active galactic nuclei (AGN), 3C 279 for calibrating the array of radio telescopes.

Event Horizon Telescope (EHT)---the Image



- Intensity of 1.3 mm (240 GHz) radio waves coming from M87 *.



Galaxy M87 and its Jet from M87*

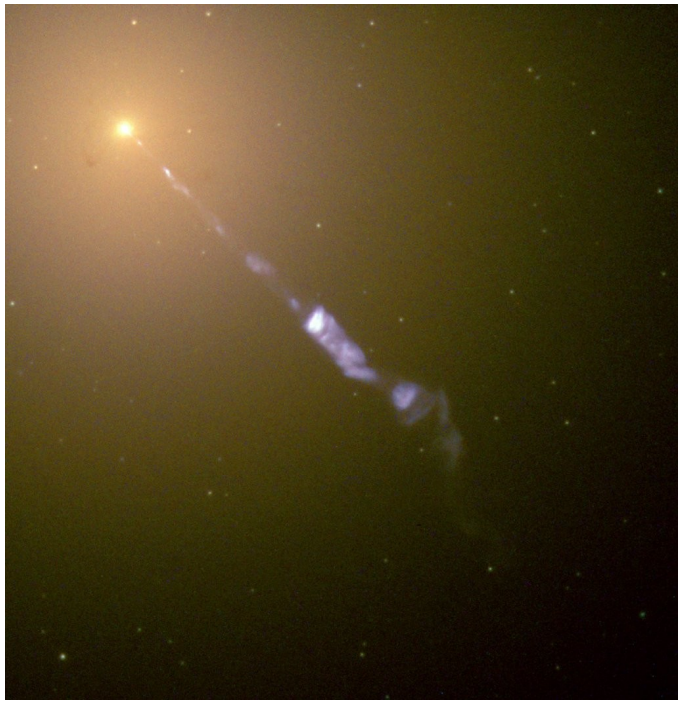
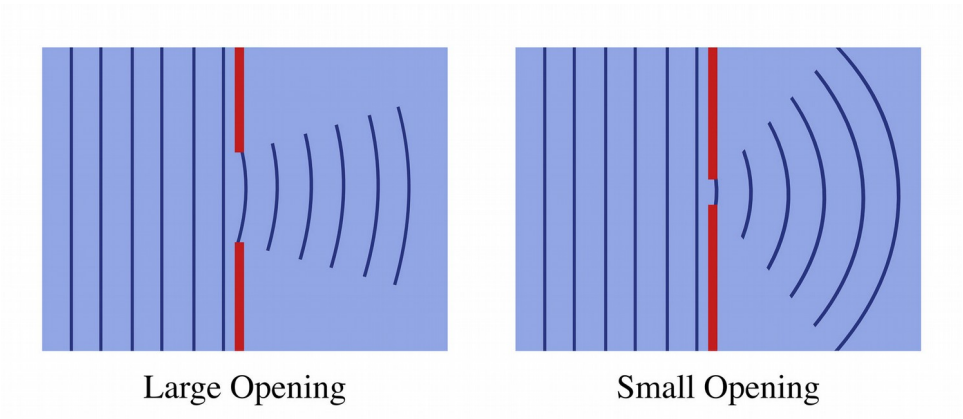


Figure 3. Top: EHT image of M87* from observations on 2017 April 11 as a representative example of the images collected in the 2017 campaign. The image is the average of three different imaging methods after convolving each with a circular Gaussian kernel to give matched resolutions. The largest of the three kernels (20 μas FWHM) is shown in the lower right. The image is shown in units of brightness temperature, $T_b = S\lambda^2/2k_B\Omega$, where S is the flux density, λ is the observing wavelength, k_B is the Boltzmann constant, and Ω is the solid angle of the resolution element. Bottom: similar images taken over different days showing the stability of the basic image structure and the equivalence among different days. North is up and east is to the left.

Diffraction

- Light's wave nature leads to the spreading of a beam of light.
  - Both for the creation of the beam and for the imaging of the beam.
- The so-called self-diffraction gives rise to an angle related to the wavelength and the beam diameter.



$$\theta \sim \frac{\lambda}{D}$$

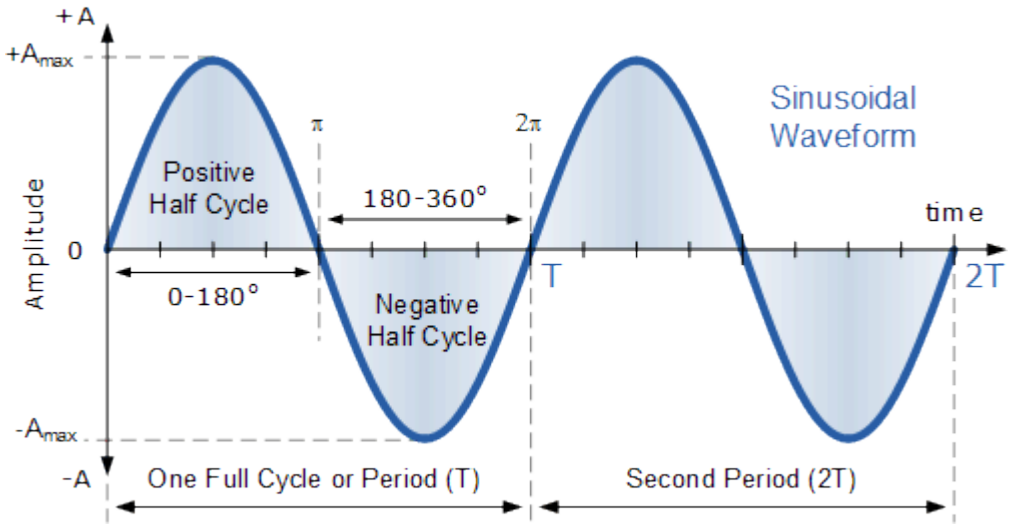
Same wavelength, different beam sizes.

Resolving Small, Far Things

- For the telescope, diffraction limits resolution of angles to $\theta \sim \frac{\lambda}{D}$
  - Baselines 160 m to 10700km and 1.3mm for ~25 micro arc-sec resolution.
- And the angular size of a (nearby-ish) object is $\theta \sim \frac{diam}{dist}$
- Sgr A* is 8.178 kpc away and the Schwarzschild diameter is about 0.16 AU, so it subtends an angle of 9.6e-11 rads, aka 19.8 micro arc-sec.
- M87* is 16.4 Mpc away and “diameter” is 257 AU for an angle of 7.6e-11 rads or 15.7 micro arc-sec.
- “Shadow” is 3*root(3) /2 = 2.6 diameters, or 51.5 and 40.8 micro arc-secs.

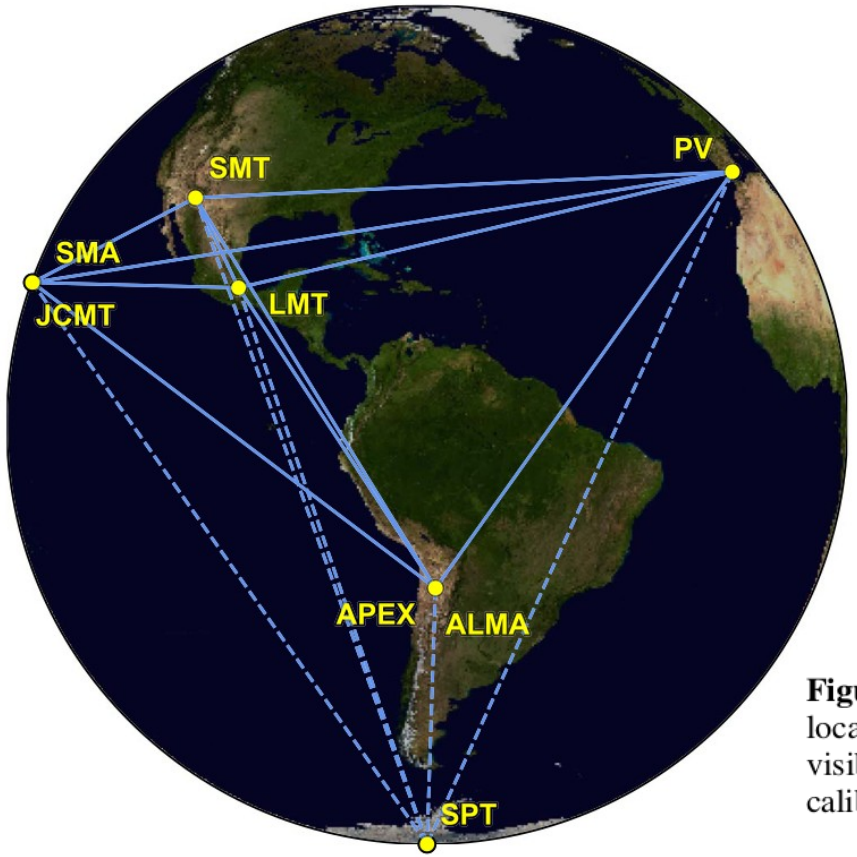
Light/Radio at λ = 1.3 mm

- 1.3 mm wavelength, is a frequency of 230 GHz, is a period of 4.3e-12 sec
- Bandwidth is important, and aggregate BW was 16 GHz (ALMA)
- Mix with 230 GHz wave to see the BW signal, so final sine wave is 16 GHz.
- Record data at a rate 64 Gbps (32x the standard VLBI array)
  - So 4 points per 16 GHz wavelength



Array of Radio Telescopes---VLBI

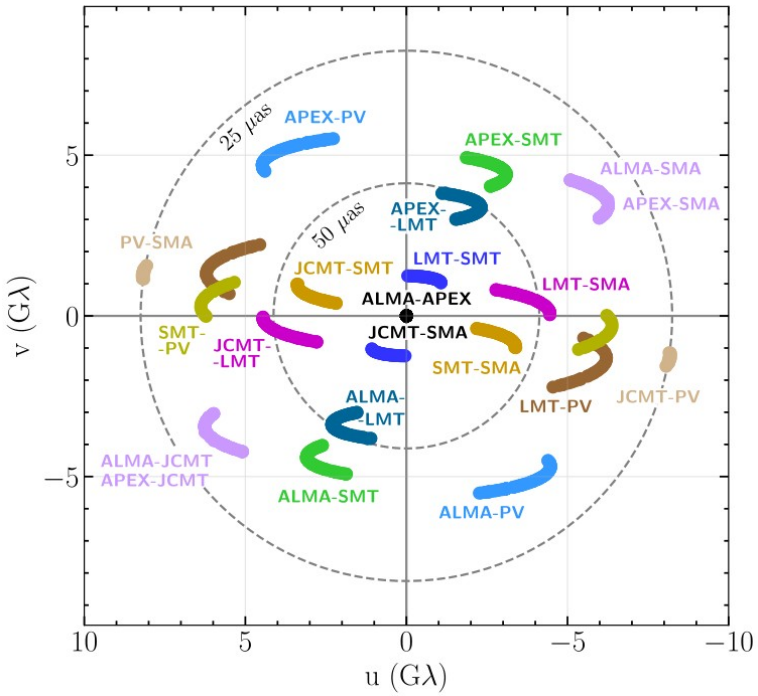
- VLBI = Very Long Baseline Interferometry
- Sometimes array of arrays of telescopes: SMT, SMA, JCMT, LMT, PV, APEX, ALMA, and SPT.



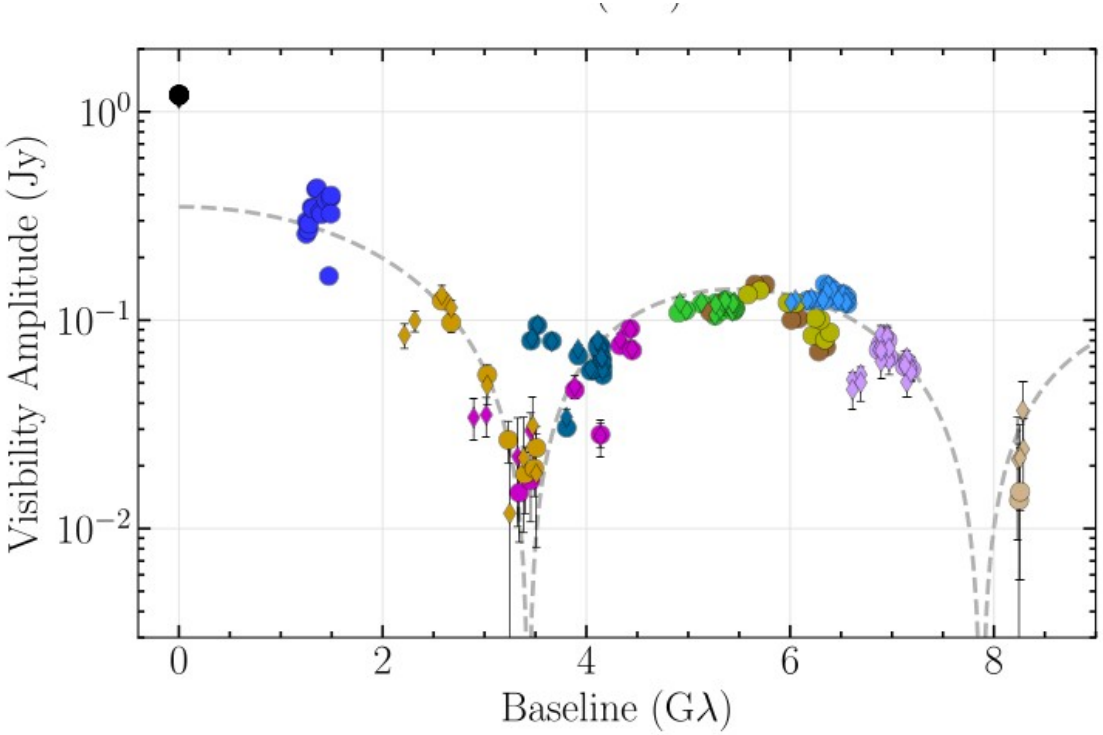
SMT = Sub-Millimeter Telescope
SMA = Sub-Millimeter Array
JCMT = James Clerk Maxwell Telescope
LMT = Large Millimeter Telescope Alfonso Serrano
PV = Pico Veleta 30 m
APEX = Atacama Pathfinder Experiment Telescope
ALMA = Atacama Large Millimeter/ Submillimeter Array
SPT = South Pole Telescope

Figure 1. Eight stations of the EHT 2017 campaign over six geographic locations as viewed from the equatorial plane. Solid baselines represent mutual visibility on M87* (+12° declination). The dashed baselines were used for the calibration source 3C279 (see Papers III and IV).

EHT Array Images Target at Same Time

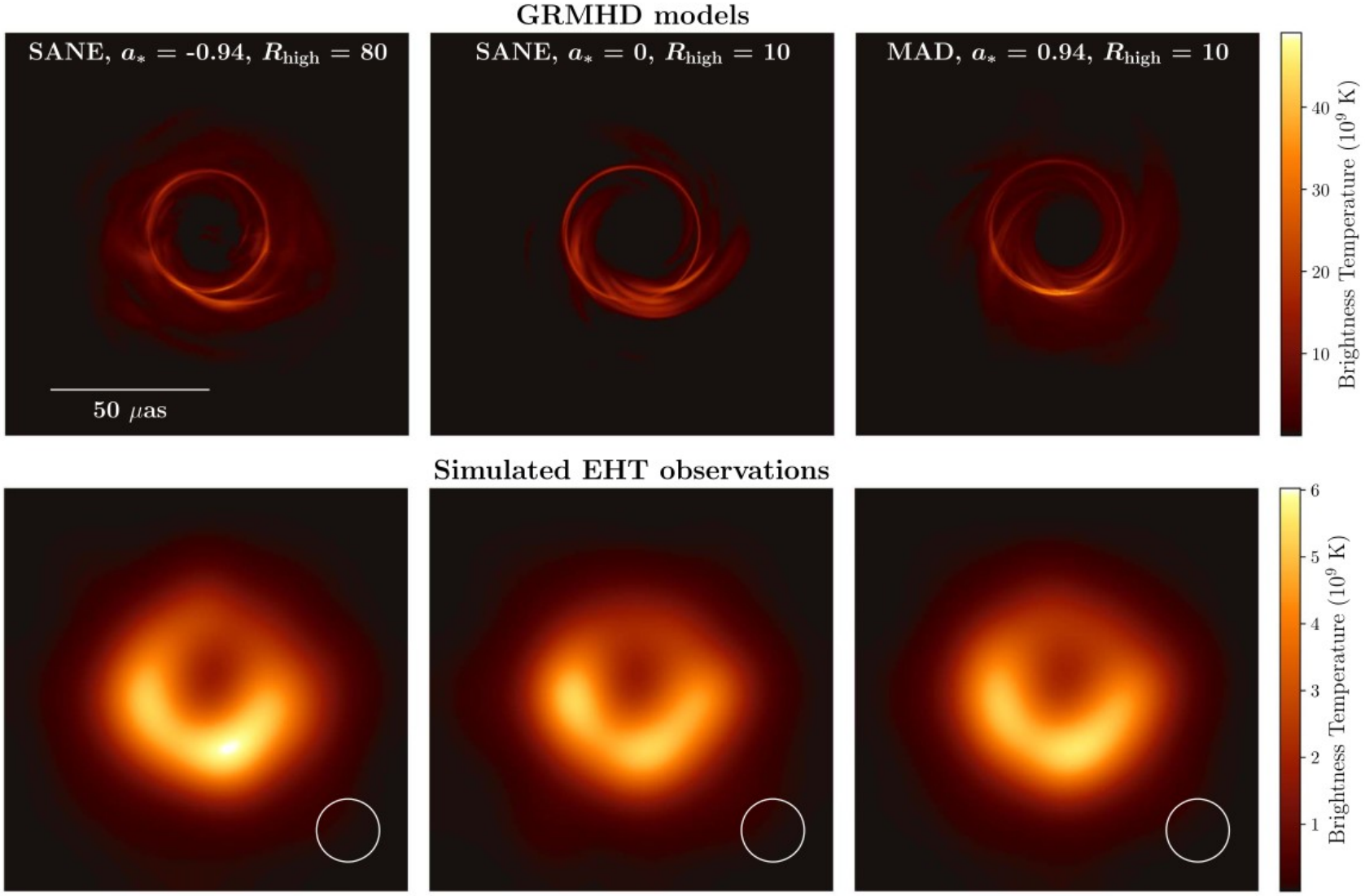


The EHT Array as a
“Radio Telescope Dish”



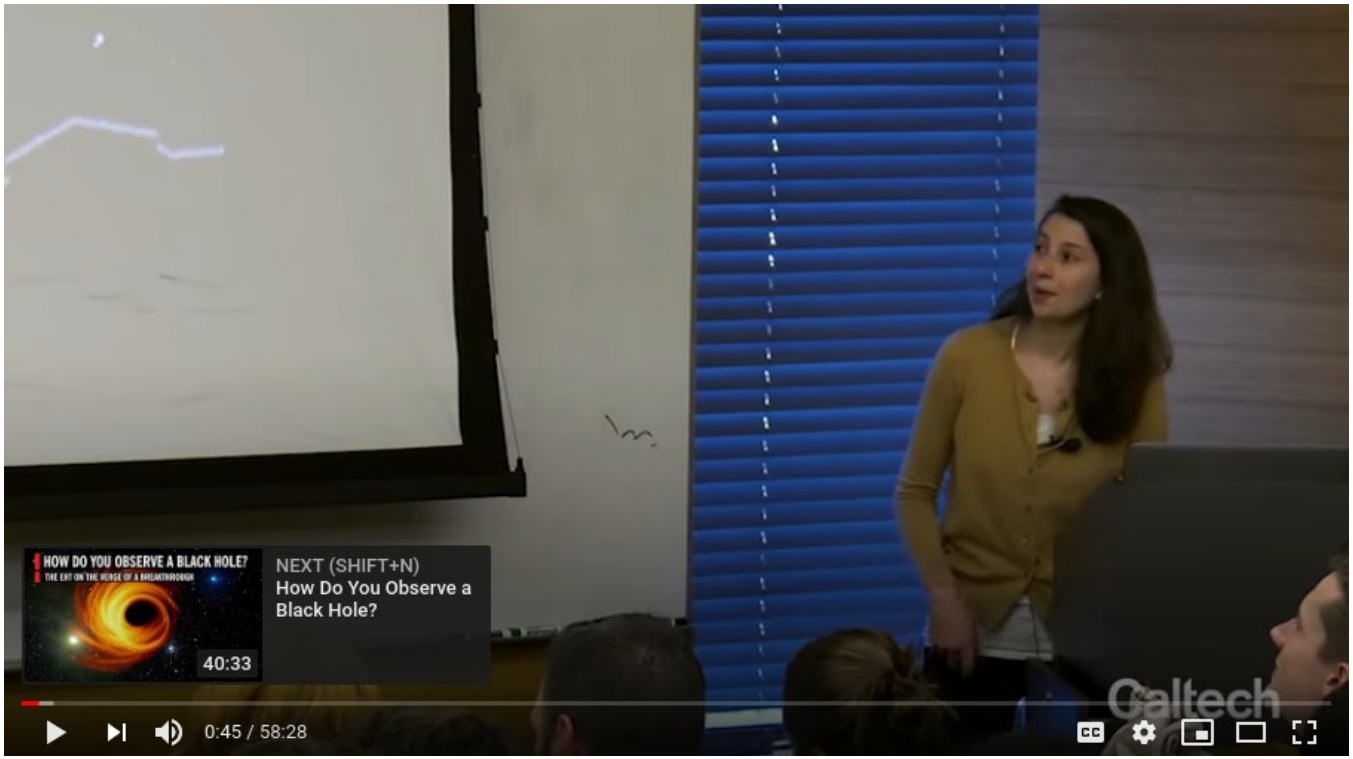
EHT Array acts as if on a mirror

Image from a lot of processing!



Katie Bouman's Talk at CalTech

- Bouman worked on the imaging analysis https://youtu.be/UGL_OL3OrCE
- aa



Gravitational Waves – aLIGO & VIRGO

VIRGO, Cuscina, Italy

LIGO, Livingston, LA

LIGO, Hanford, WA

Gravitational Waves – aLIGO & VIRGO

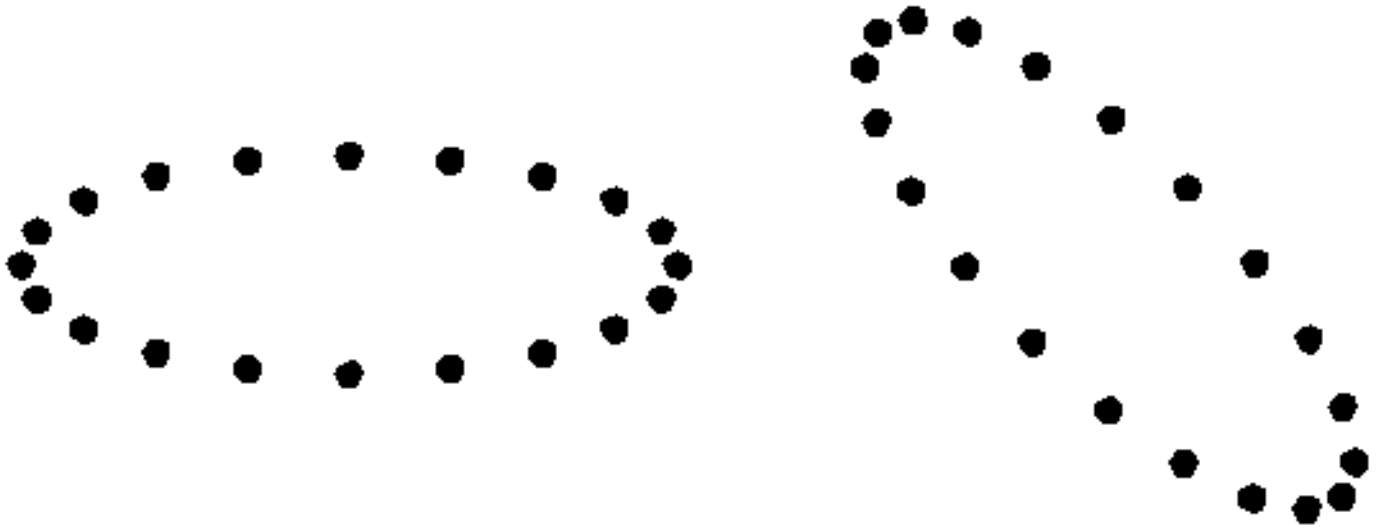
- aLIGO = Advanced Laser Interferomter Gravitational-Wave Observatory, https://www.ligo.org/ and https://www.ligo.caltech.edu/
- Restarted observations on 1 April 2019, so-called “O3” run.
- Seeing a binary black hole merger every week, more or less, https://gracedb.ligo.org/latest/

Gravitational Waves – In a Picture

- Source of Gravitational Waves is mass-energy motion that is not spherically symmetric.
- Strong GW sources have small sizes, high mass, and fast motion.
- The first “order” in the expansion is quadrupole radiation.
  - In Electricity and Magnetism it is dipole radiation.

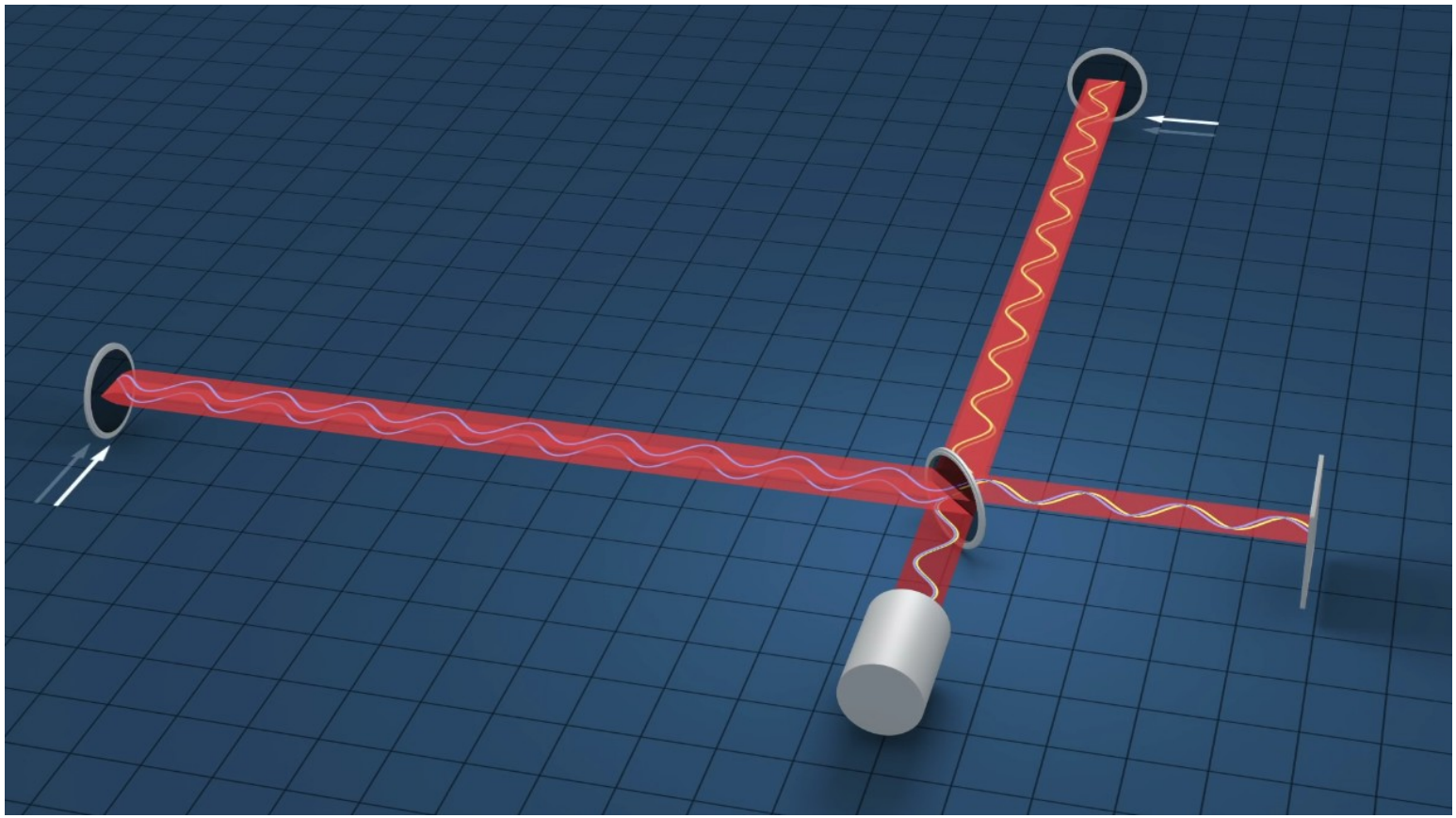
Gravitational Waves – In a Picture

- Two modes, + and X
- Dots are masses hanging out in space with little self-attraction. They are NOT a metal ring! That is bound by atomic forces and the effect of the GW is miniscule.



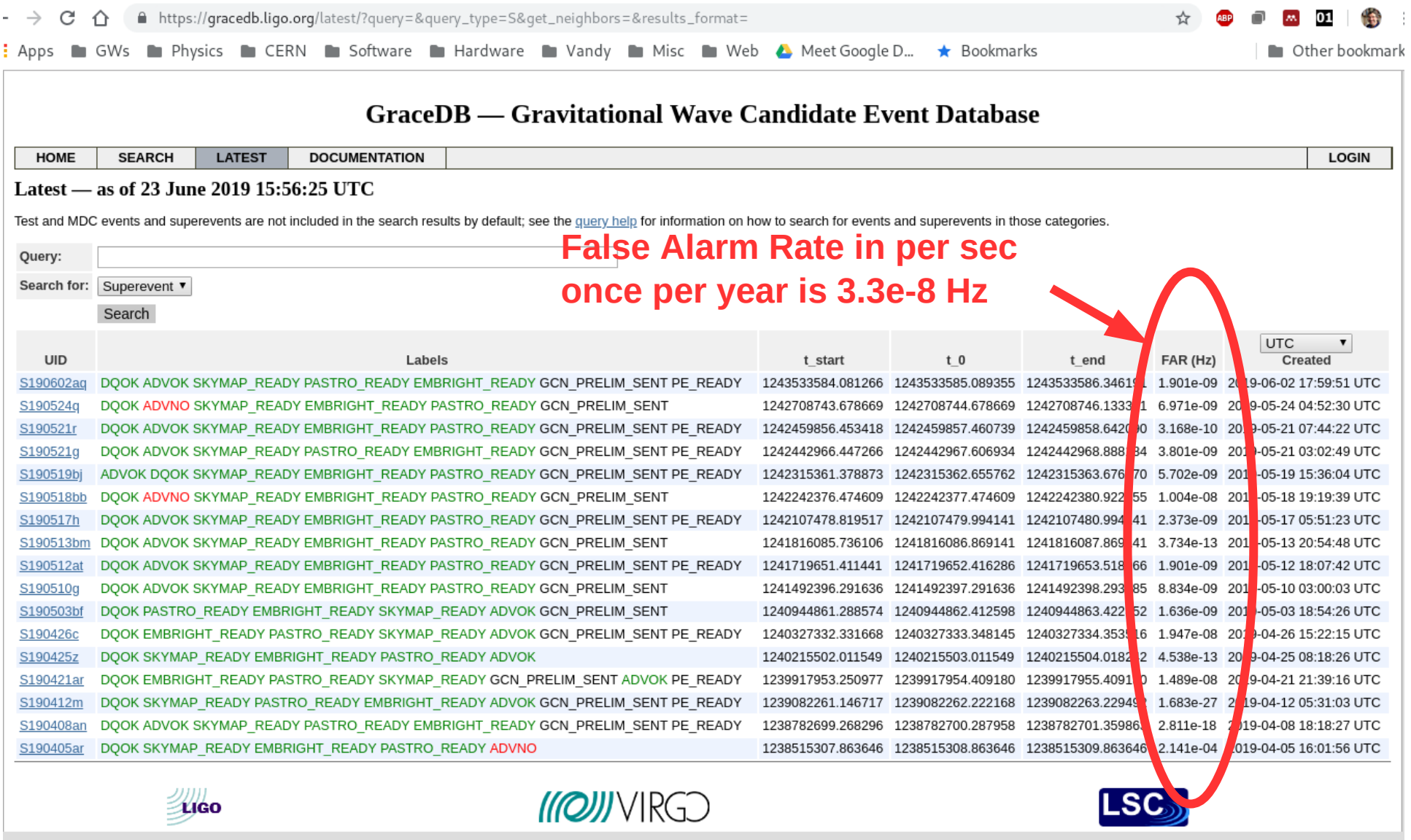
Big Michelson Interferometer, 4 km arms

- YouTube link https://youtu.be/tQ_teIUb3tE



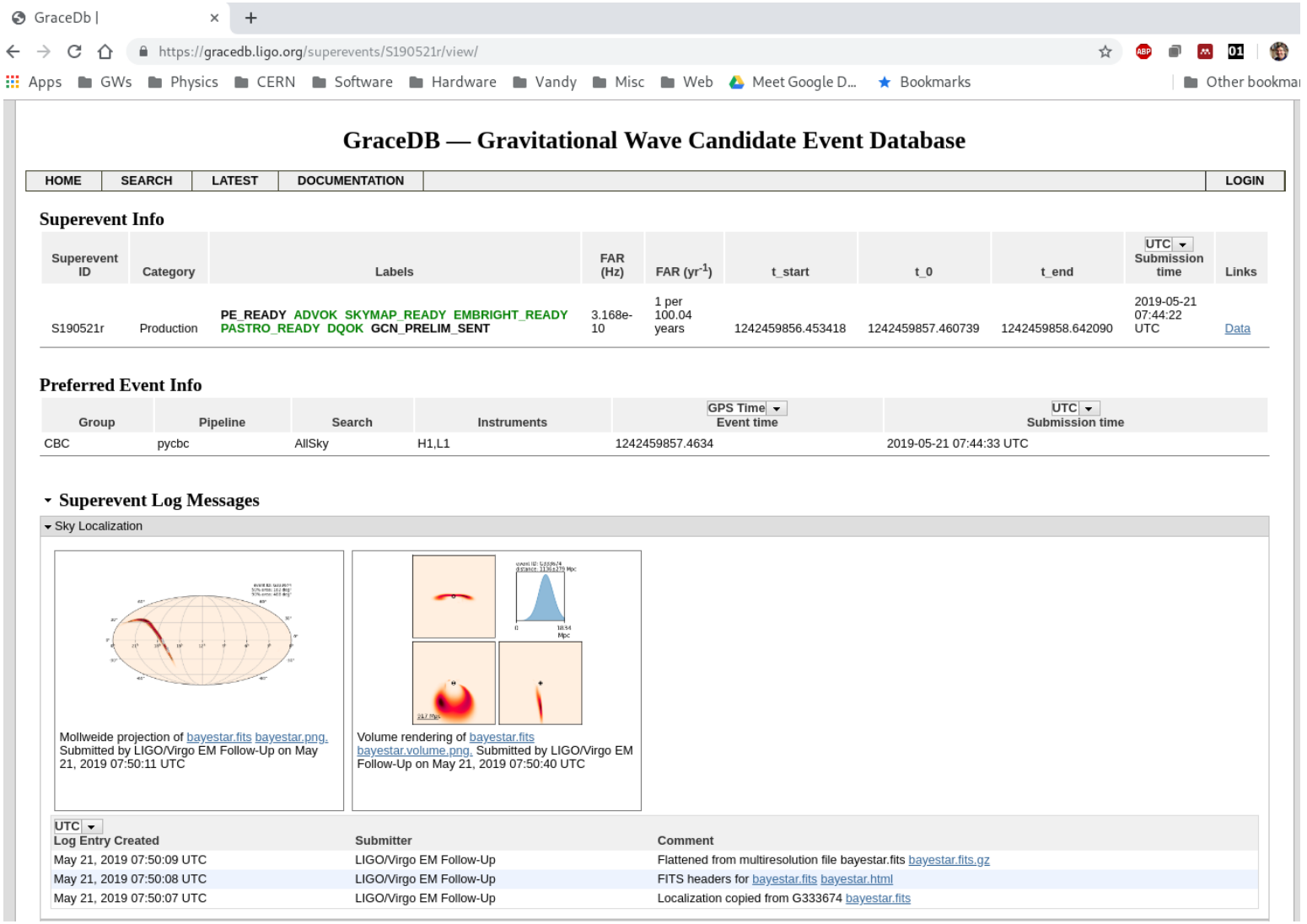
LIGO GraceDB Latest

- Gracedb Latest at https://gracedb.ligo.org/latest/



LIGO GraceDB Latest – S190521r

- FAR 1/100yrs https://gracedb.ligo.org/superevents/S190521r/view/



GraceDb |

https://gracedb.ligo.org/superevents/S190521r/view/

Apps GWs Physics CERN Software Hardware Vandy Misc Web Meet Google D... Bookmarks Other bookmar

GraceDB — Gravitational Wave Candidate Event Database

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Superevent Info

Superevent ID	Category	Labels	FAR (Hz)	FAR (yr^{-1})	t_start	t_0	t_end	UTC Submission time	Links
S190521r	Production	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	3.168e-10	1 per 100.04 years	1242459856.453418	1242459857.460739	1242459858.642090	2019-05-21 07:44:22 UTC	Data

Preferred Event Info

Group	Pipeline	Search	Instruments	GPS Time Event time	UTC Submission time
CBC	pycbc	AllSky	H1,L1	1242459857.4634	2019-05-21 07:44:33 UTC

Superevent Log Messages

Sky Localization

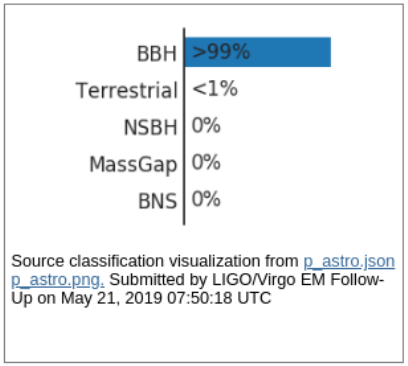
Mollweide projection of bayestar.fits bayestar.png. Submitted by LIGO/Virgo EM Follow-Up on May 21, 2019 07:50:11 UTC

Volume rendering of bayestar.fits bayestar.volume.png. Submitted by LIGO/Virgo EM Follow-Up on May 21, 2019 07:50:40 UTC

UTC Log Entry Created	Submitter	Comment
May 21, 2019 07:50:09 UTC	LIGO/Virgo EM Follow-Up	Flattened from multiresolution file bayestar.fits bayestar.fits.gz
May 21, 2019 07:50:08 UTC	LIGO/Virgo EM Follow-Up	FITS headers for bayestar.fits bayestar.html
May 21, 2019 07:50:07 UTC	LIGO/Virgo EM Follow-Up	Localization copied from G333674 bayestar.fits

LIGO GraceDB Latest – S190521r

▾ EM Followup



Source classification visualization from p_astro.json p_astro.png. Submitted by LIGO/Virgo EM Follow-Up on May 21, 2019 07:50:18 UTC

UTC

Log Entry Created	Submitter	Comment
May 21, 2019 08:17:50 UTC	LIGO/Virgo EM Follow-Up	New VOEvent S190521r-2-Initial.xml
May 21, 2019 07:50:19 UTC	LIGO/Virgo EM Follow-Up	New VOEvent S190521r-1-Preliminary.xml

▾ EM Observations

No EM observation entries so far.

▸ Full Superevent Log

Links

- aa

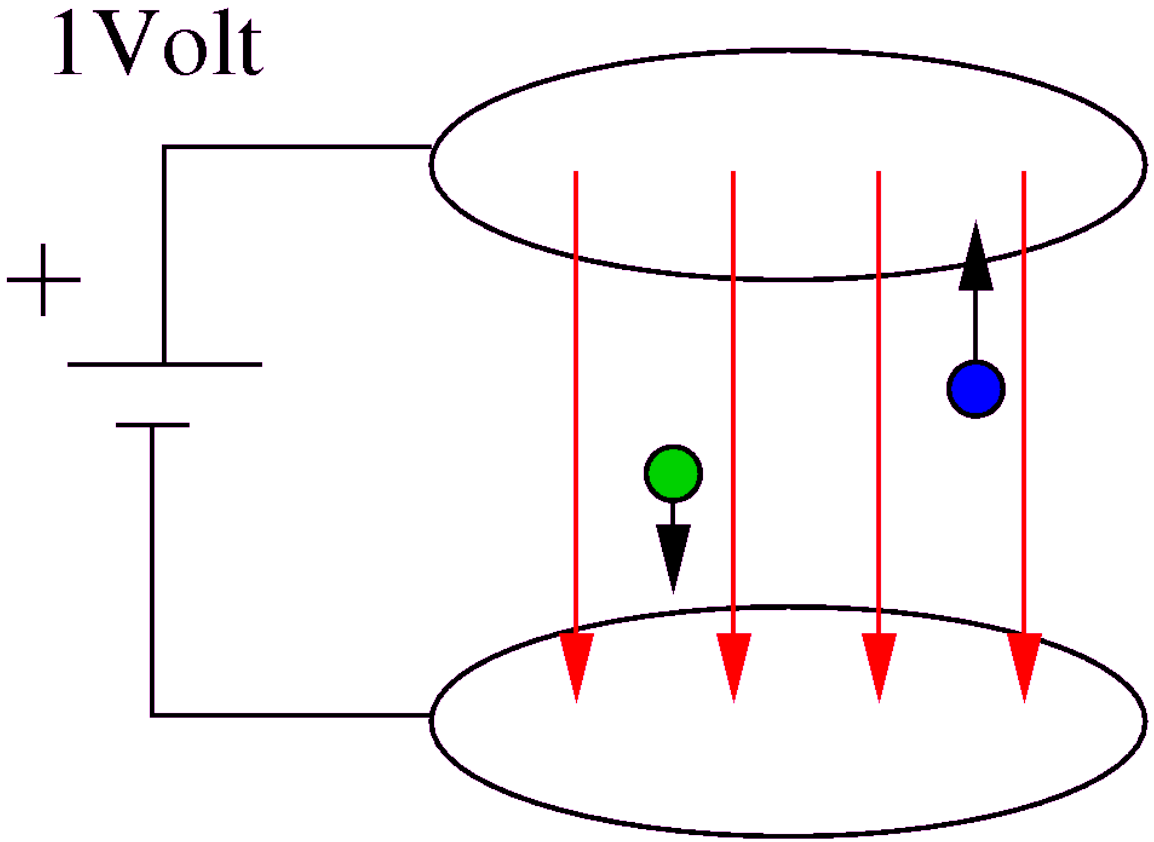
Backup

SI Prefixes

Table 5. SI prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deka	da	10^{-24}	yocto	y

Units?



- Proton, heavy, +e
- Electron, light, –e

Speed of Light

Fastest possible speed is the speed of light in vacuum.

Defined as $299792458\,\mathrm{m/s}$

$3.0 \times 10^8\,\mathrm{m/s}$

$30\,cm/ns$

$300\,m/\mu s$ $300\,\mu m/ps$