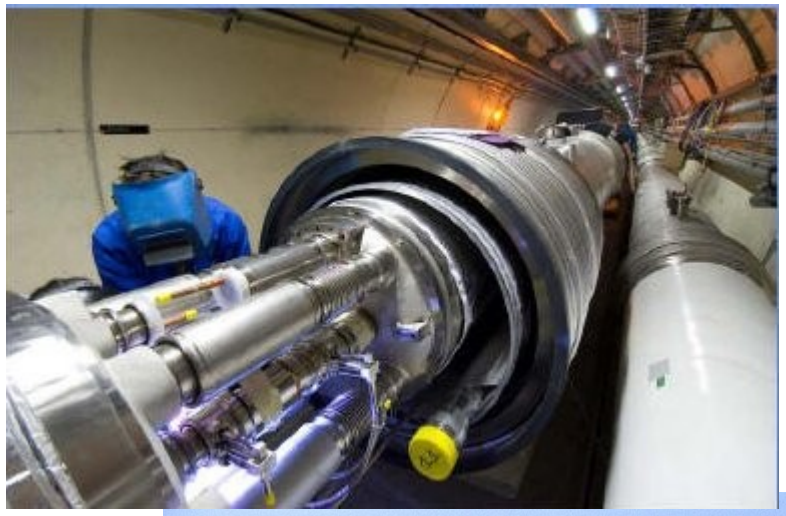
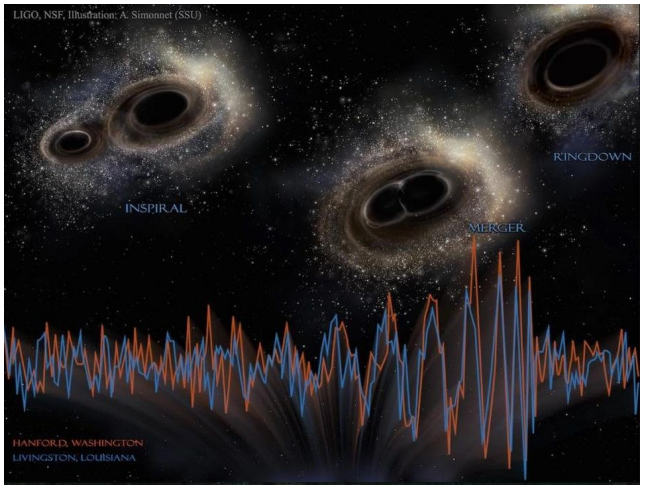
CERN/LHC/CMS, LIGO, Astro---Misc



Bill Gabella

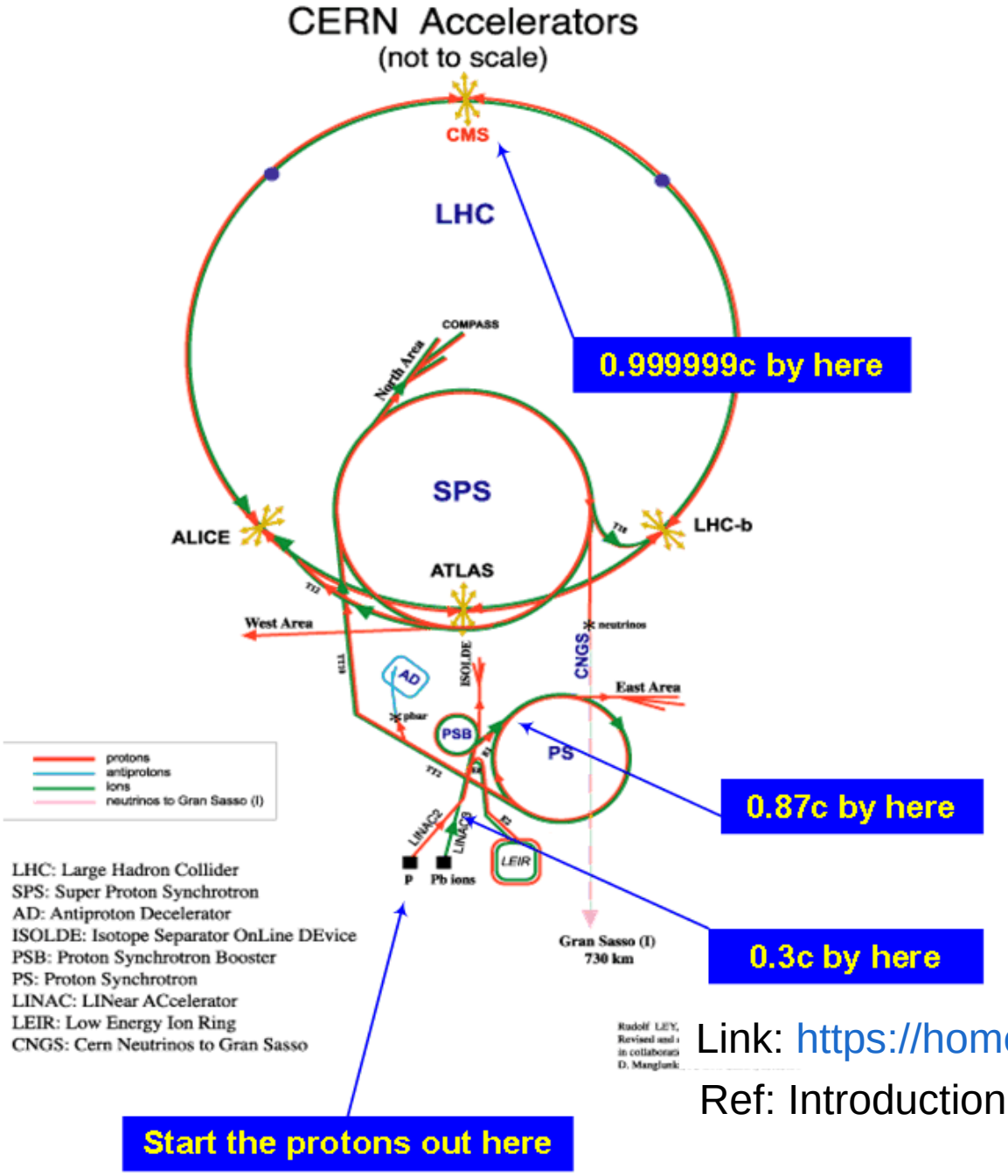
Monday 22 June 2020

Vanderbilt-QuarkNet Workshop



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

Large Hadron Collider (LHC)



Energies:

Linac 50 MeV

PSB 1.4 GeV

PS 28 GeV

SPS 450 GeV

LHC 6.5 TeV

Link: https://home.cern/topics/large-hadron-collider

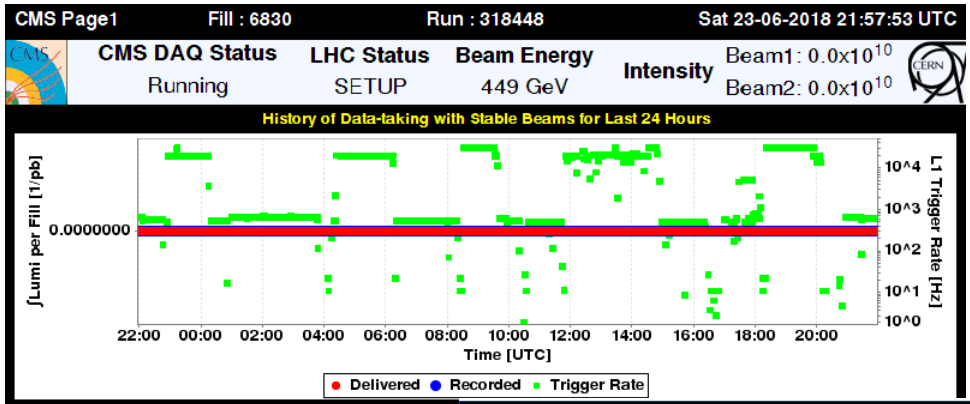
Ref: Introduction to Accelerators, Elena Wildner, CERN

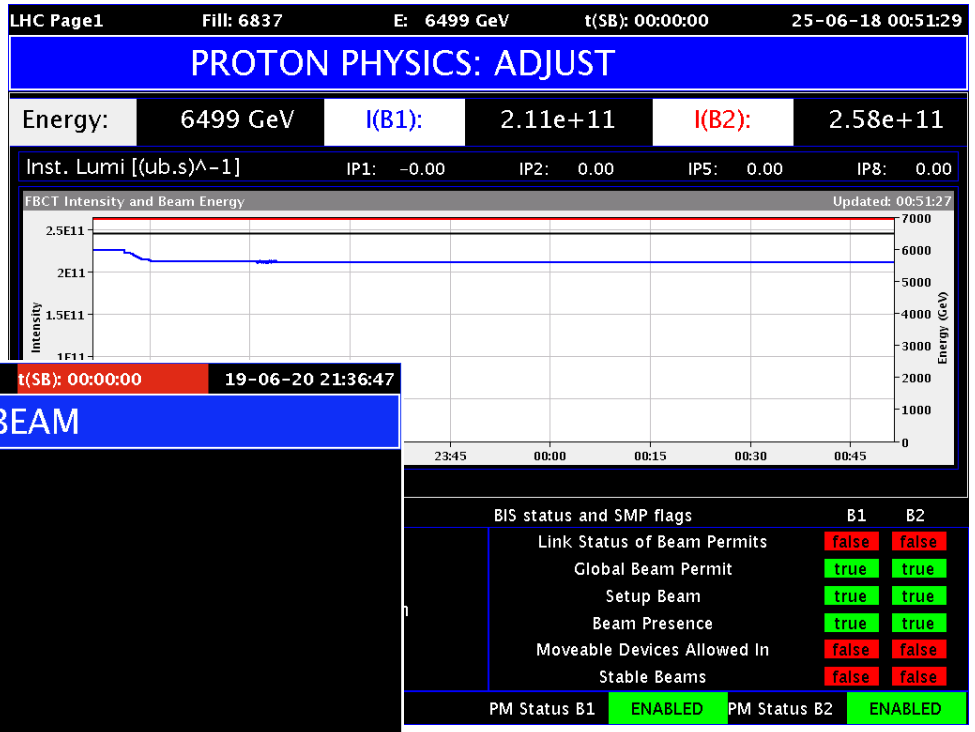
LHCParameters

Circumference	26659 m
Dipole operating temp	1.9 deg K
Main RF frequency	400.8 MHz
“Bucket,” 1/frequency	2.5 ns
Energy per beam	6.5 TeV, operating
Dipole Magnetic Field	7.7 T
Ions Energy per nucleon	2.56 TeV/n = 6.5*82/208 (Pb-208)
no. of protons	1.2e11 per bunch
no. of bunches	<= 2604/2748
bunch length, 4sigma	1-1.25 ns
bunch size, x & y at IP, 1 sigma	52 x 66 microns

Ref: www.cern.ch

Current Status Op Vistar – Long Shudown 2





Click Here

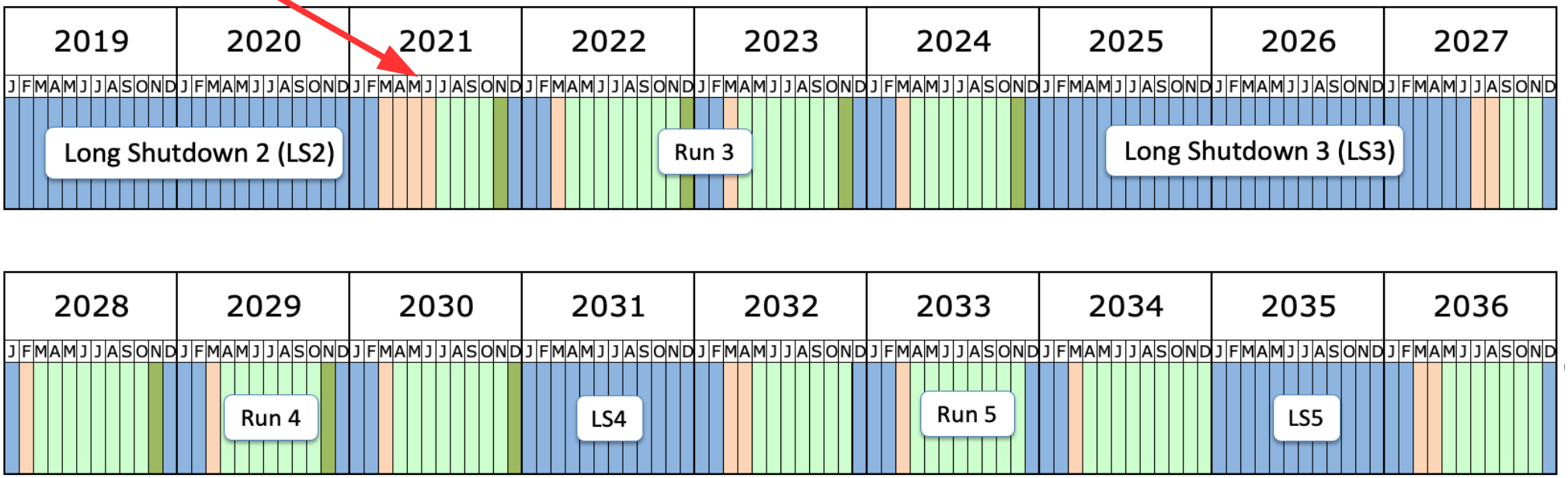
https://op-webtools.web.cern.ch/vistar/vistars.php?usr=LHC1

Long Shutdown 2 Goals...

- Upgrade the whole LHC injector chain;
- Energy to 7 TeV? 20% higher luminosity?
- Maintenance on the LHC and the Detectors;
- Start on aspects of the *Accelerator Consolidation Project* and
- the *HL-LHC*, aka the High-Luminosity LHC (even more protons per bunch and/or more bunches.
- LS2 runs to Spring 2021 (see next slide, Will's talk)
- LS3 starts (maybe) 2024 and runs 2.5 years until mid-2026.

LHC Long-term Schedule 2019-2036

Proton Collisions Start, "LHC Start May 2021"



Long Shutdown 2, started **Dec 2018** to **May 2021**, main purpose is LHC Injectors Upgrade

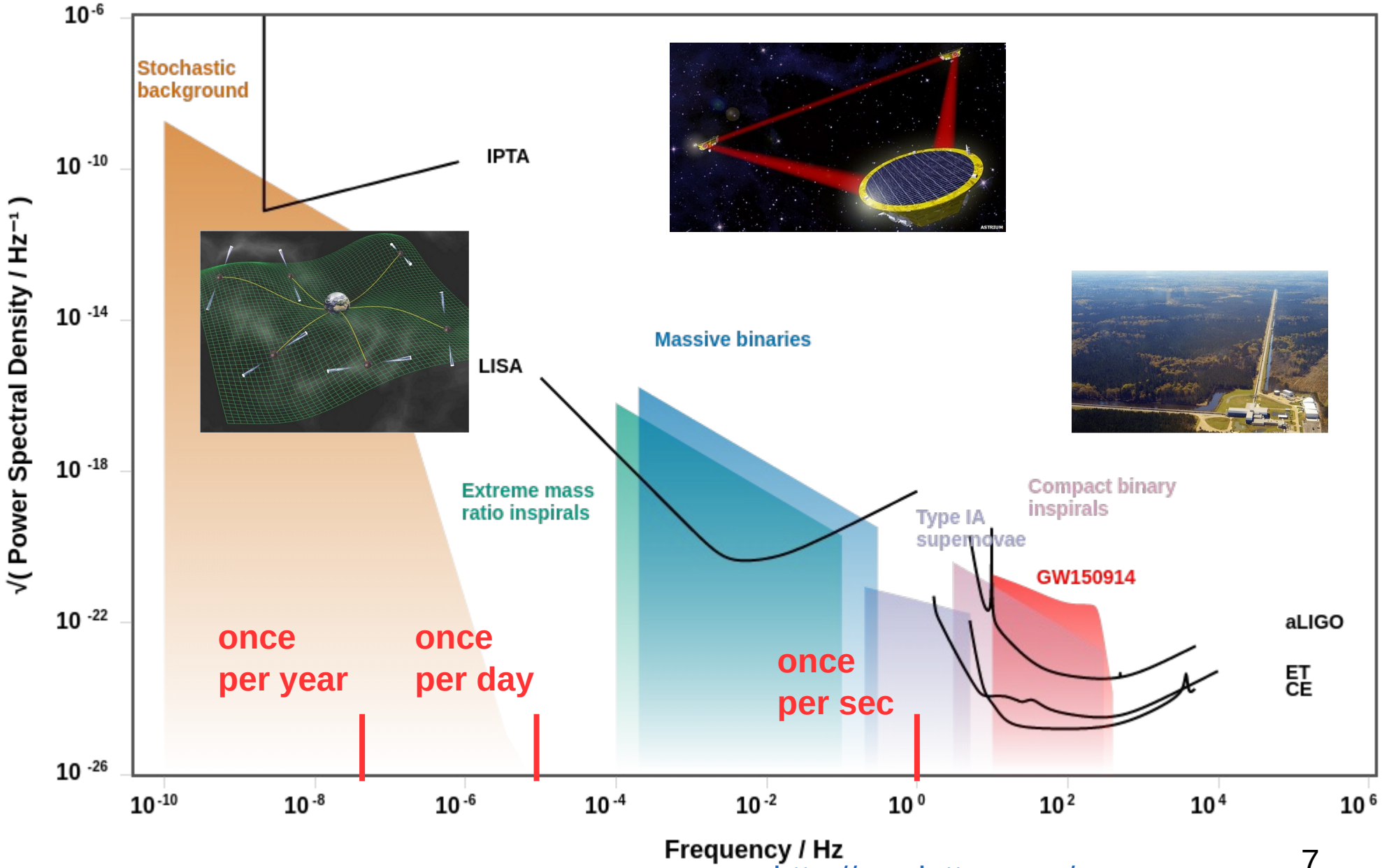
LHC Status

LHC Schedule, 13 Dec 19

Long term schedule

https://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-long-term.htm

Gravitational Waves – the whole shebang



http://gwplotter.com/

Gravitational Waves – aLIGO & VIRGO

VIRGO, Cascina, Italy

LIGO, Livingston, LA

LIGO, Hanford, WA

Gravitational Waves – aLIGO & VIRGO

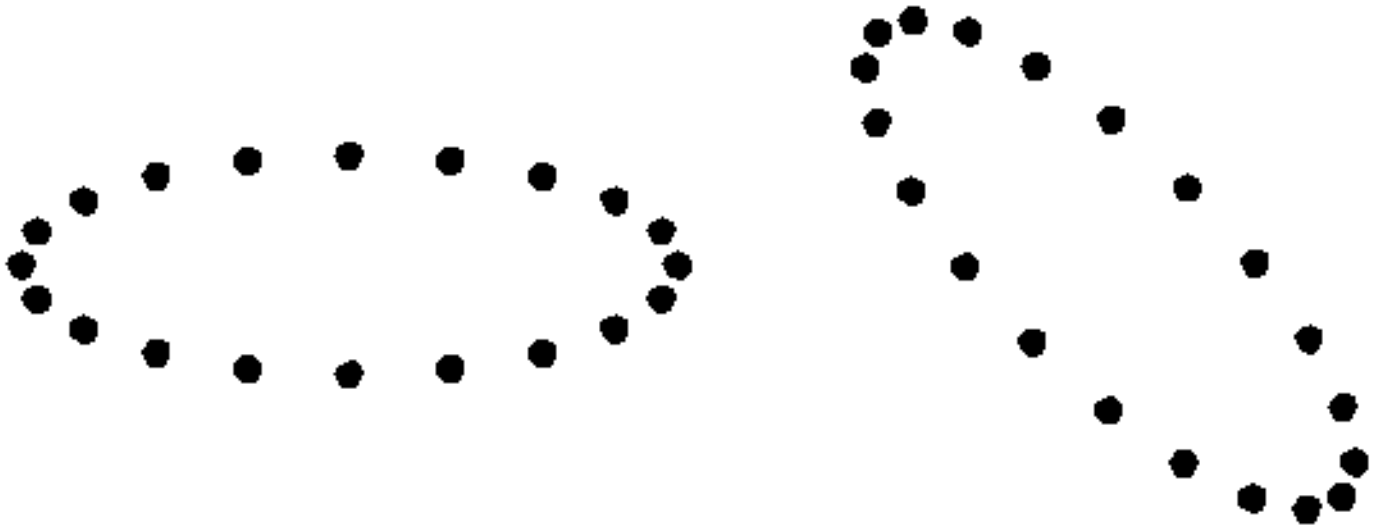
- **Karan Jani** is a member of LIGO and LIGO Scientific Collaboration, talks tomorrow morning.
- aLIGO = Advanced Laser Interferometer Gravitational-Wave Observatory, https://www.ligo.org/ and https://www.ligo.caltech.edu/
- Virgo, http://www.virgo-gw.eu/, in Cascina, Italy, in a network with Hanford and Livingston Observatories in LIGO
- Restarted observations on 1 April 2019, so-called “O3” run. Paused in March 2020 for covid-19.
- Seeing a binary black hole merger every week, more or less, https://gracedb.ligo.org/latest/
- Continuing evidence of “unexpected” black hole masses, and caught a large mass ratio event GW190412, 30 and 8 Msol.

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 the first “order” is dipole radiation.

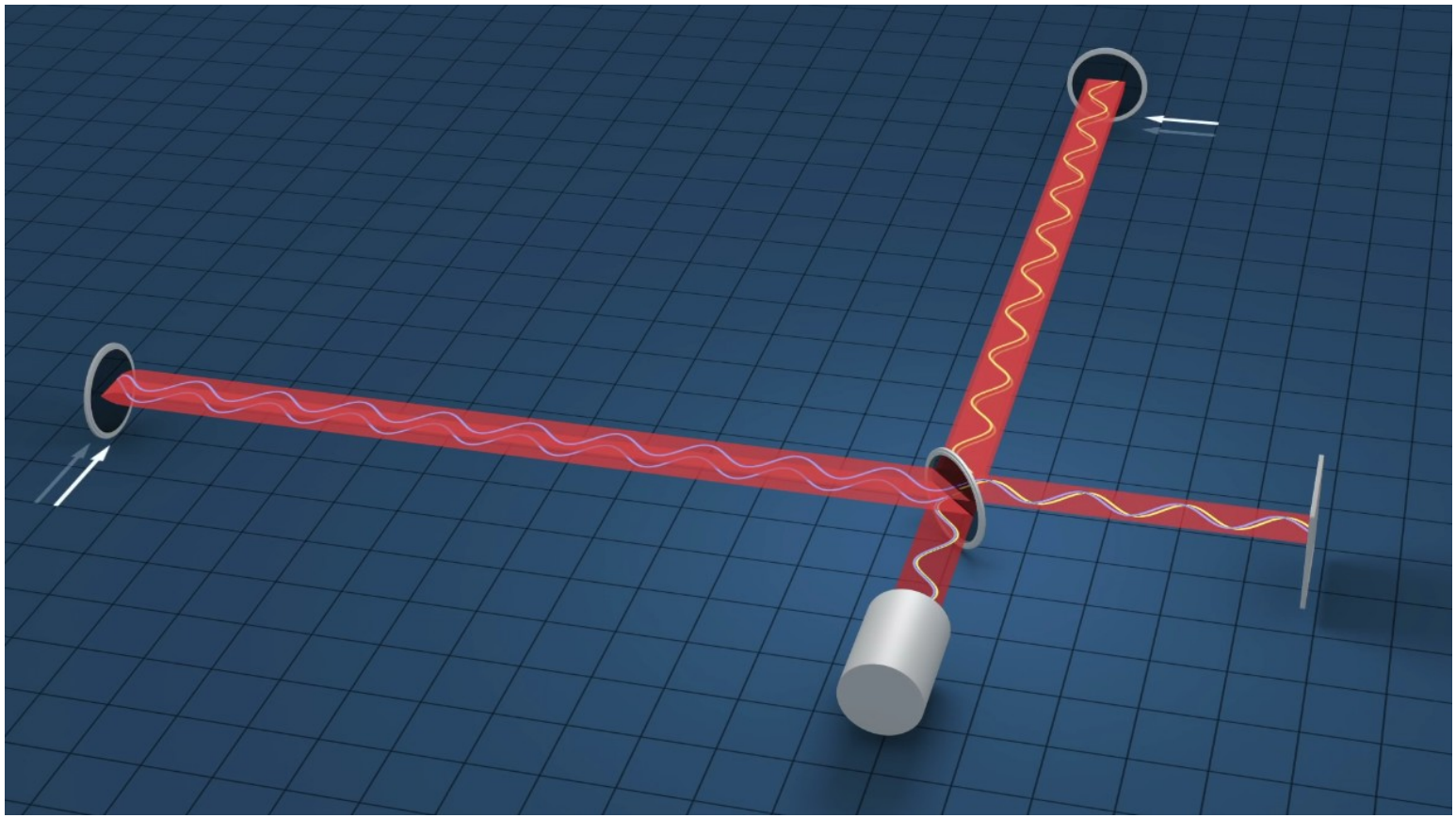
Gravitational Waves – In a Picture

- 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

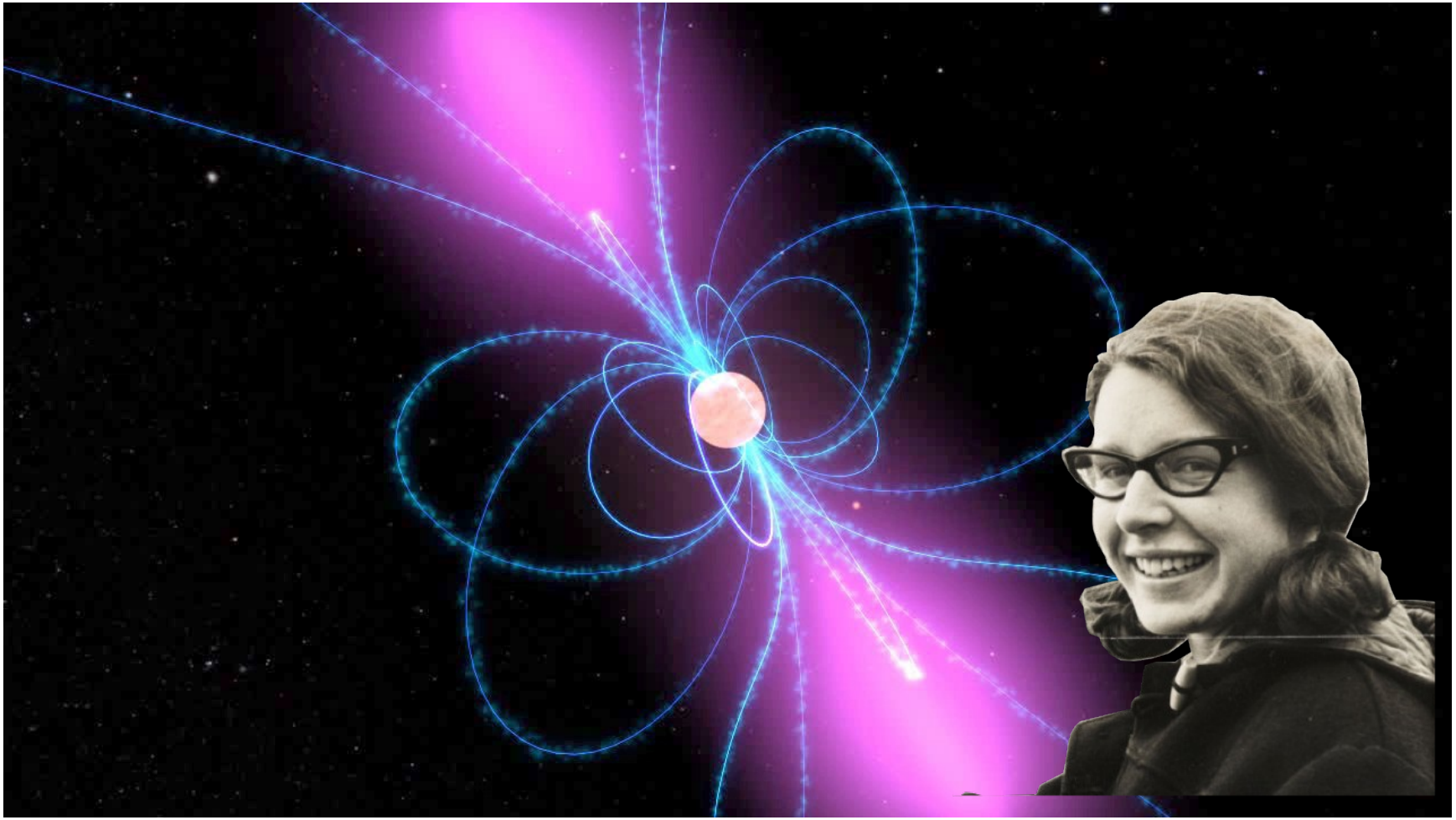


Pulsar Timing Arrays, ex. Nanograv

- **Steve Taylor** recently joined Vanderbilt's Physics and Astronomy Department and with the Nanograv collaboration will talk at 11:10am today!
- Looking at the lowest frequency (longest timescale sources) gravitational waves.
- Collection of fast millisecond pulsars as good clocks and look for a delay or advance of a pulse relative to another pulsar in a different place in the sky (**Hellings Downs curve**).
- Links:
  - NANOGrav collaboration
  - International PTA
  - Pulsar Search Collaboratory
  - ATNF Pulsar Catalog

Pulsars

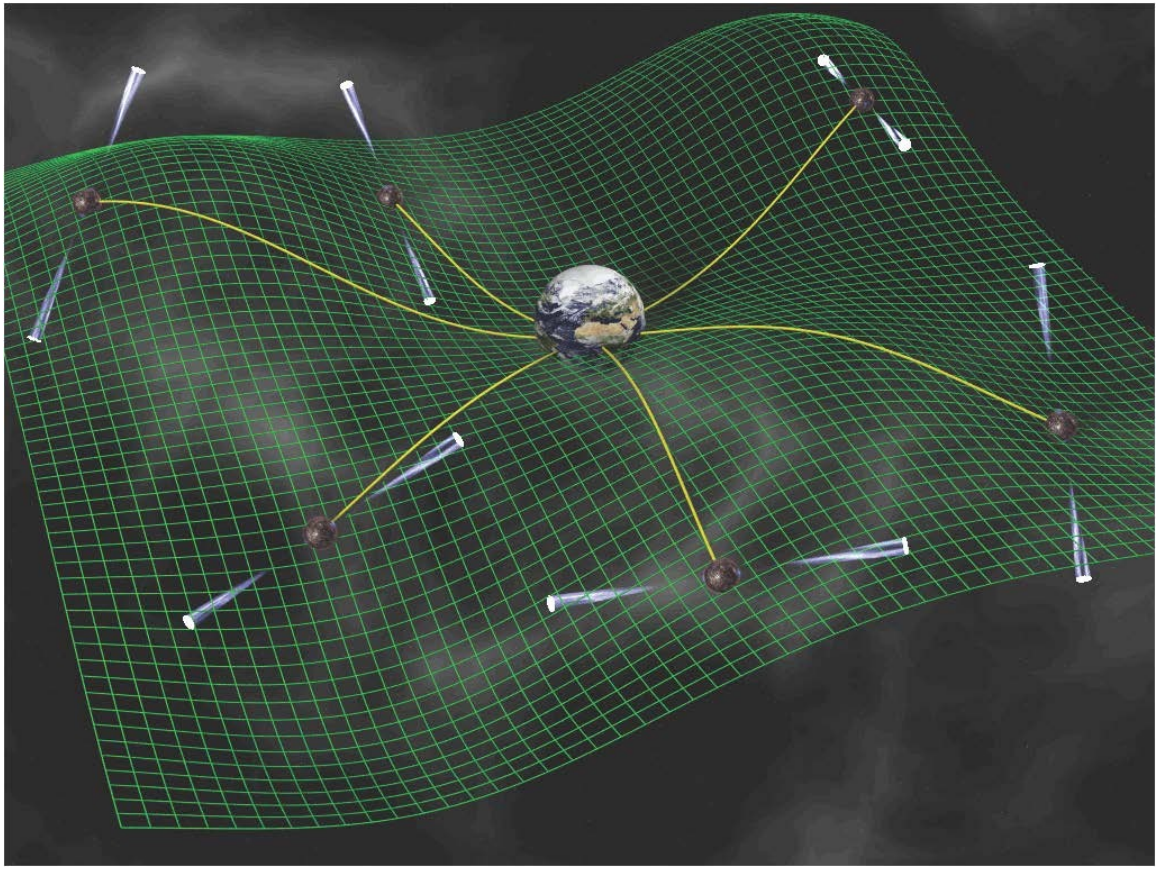
- Pulsars are Neturon Stars “aimed” at us; lighthouse effect



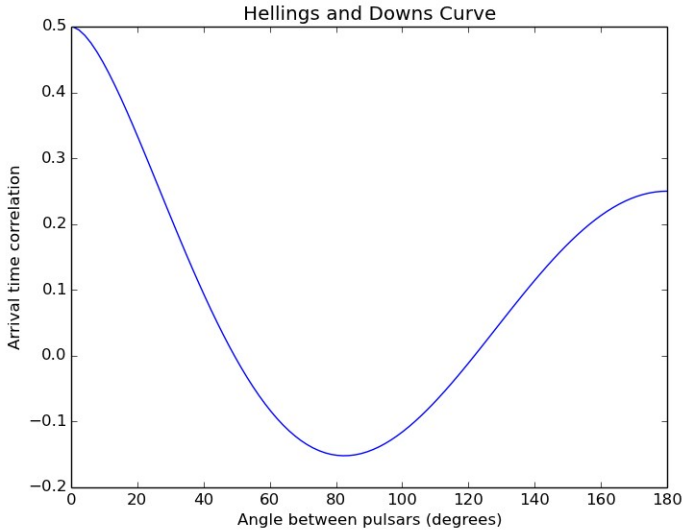
Jocelyn Bell Burnell, 1967

Timing Array

- Collect the best (stable and predictable), fastest pulsars into a network of “clocks.”
- How look for a hiccup of a passing gravitational wave.



Clocks at different angles are correlated in timing, Hellings Downs curve.



Goals

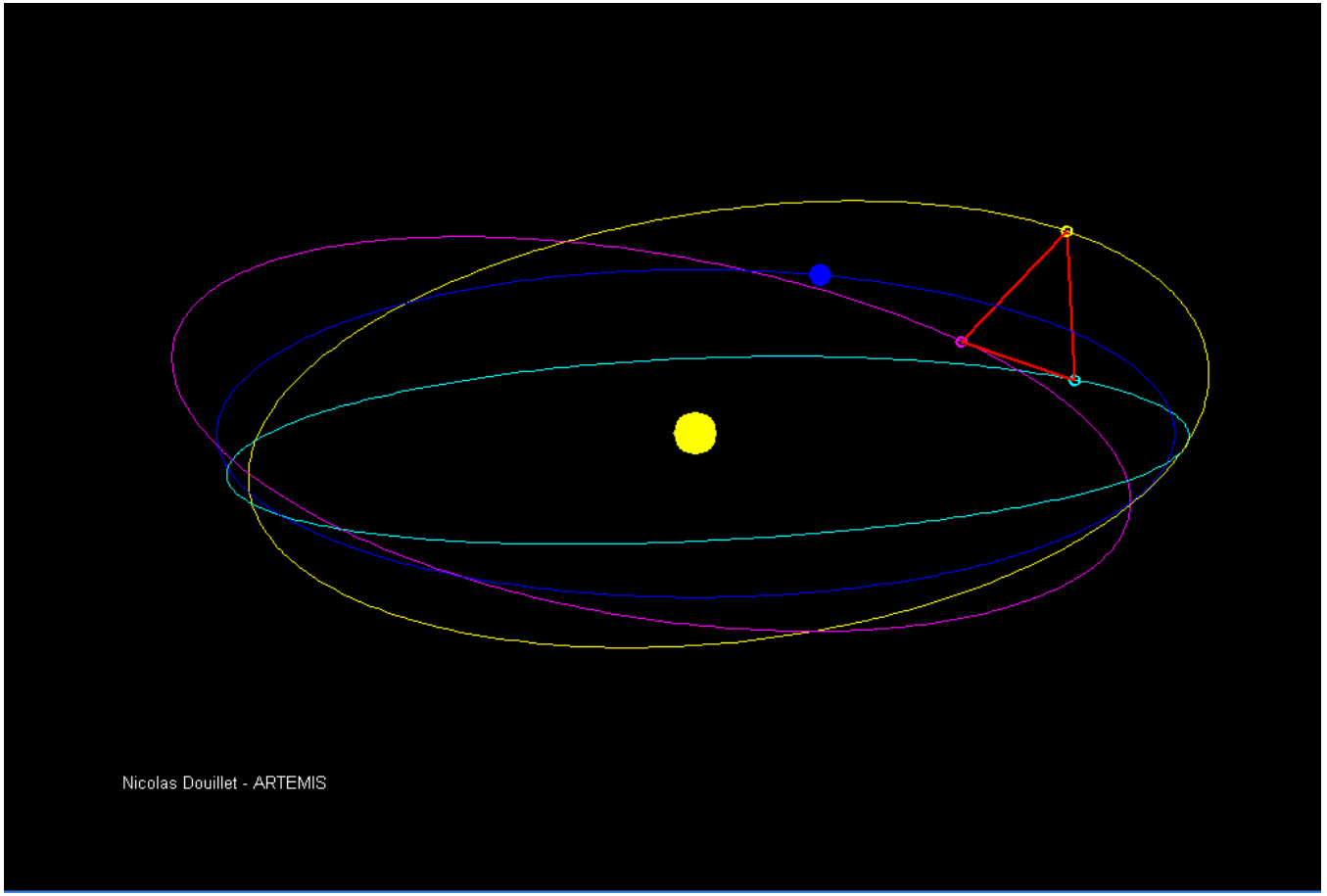
- Steve knows better...
- Discover the stochastic background gravitational waves of the universe in their frequency band, ~1 nHz (or once per 31.7 years, or sizes using the speed-of-light of L~9.7 pc NOW, much smaller in the past)
- When that is understood start looking for new things.

Laser Interferometric Space Antenna (LISA)

- Space-based mission, in the R&D and building phase.
  - Trio of spacecraft with laser links
  - 2.5 billion meter arm length (1 AU is 150 billion meters)
  - Orbits the sun slightly behind Earth in about the same orbit
  - Lifetime 4 years, can be extended to 10 years
- European Space Agency mission with significant effort and money from NASA.
- Launches in 2034, or thereabouts.
- Looking at the “middle” frequency (mid-range timescale sources) gravitational waves, 10^{-4} to 1 Hz
- Sources: medium size binary black hole mergers, stellar size BHs orbiting, small objects orbiting and merging with supermassive BHs (so-called EMRIs)

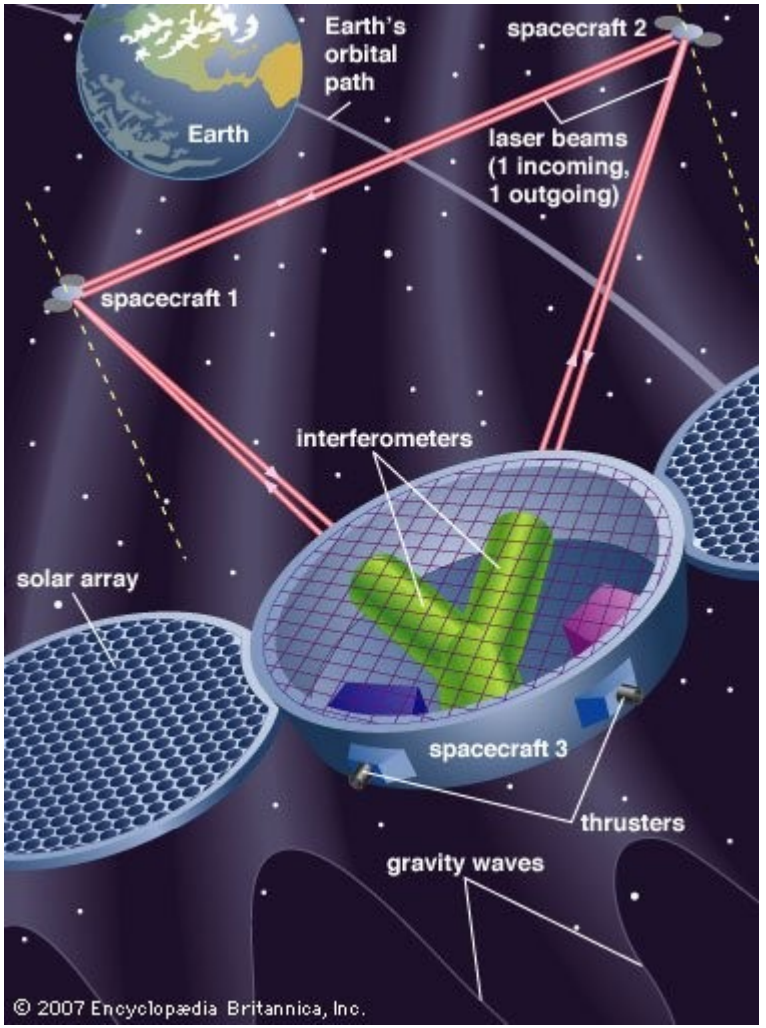
LISA

- Orbit



LISA

- Two bi-directional lasers on each spacecraft
- Timing delays are the signal
  - Lots of interesting algebraic relations among the different times



source https://www.britannica.com/science/gravitational-wave

LISA

- Links:
  - LISA Mission
  - ESA LISA site
  - NASA LISA site

Links

- aa

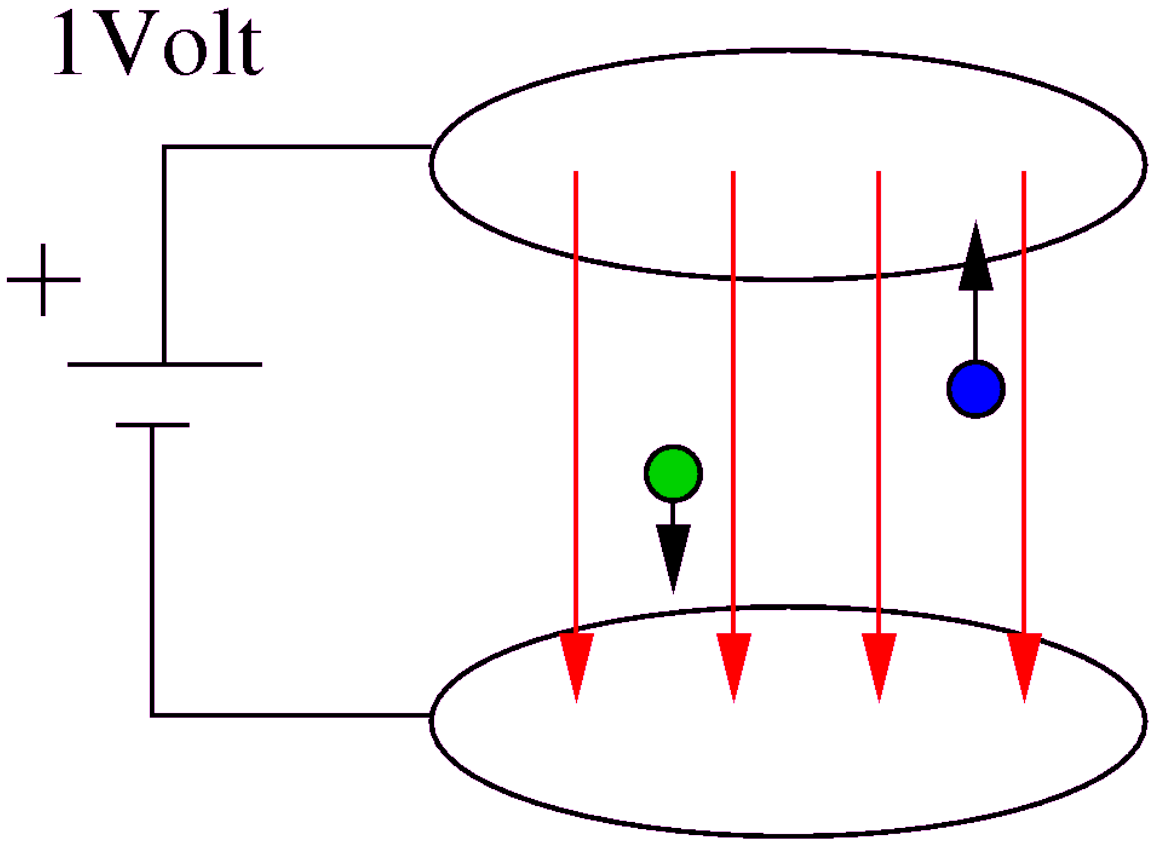
Backup

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.

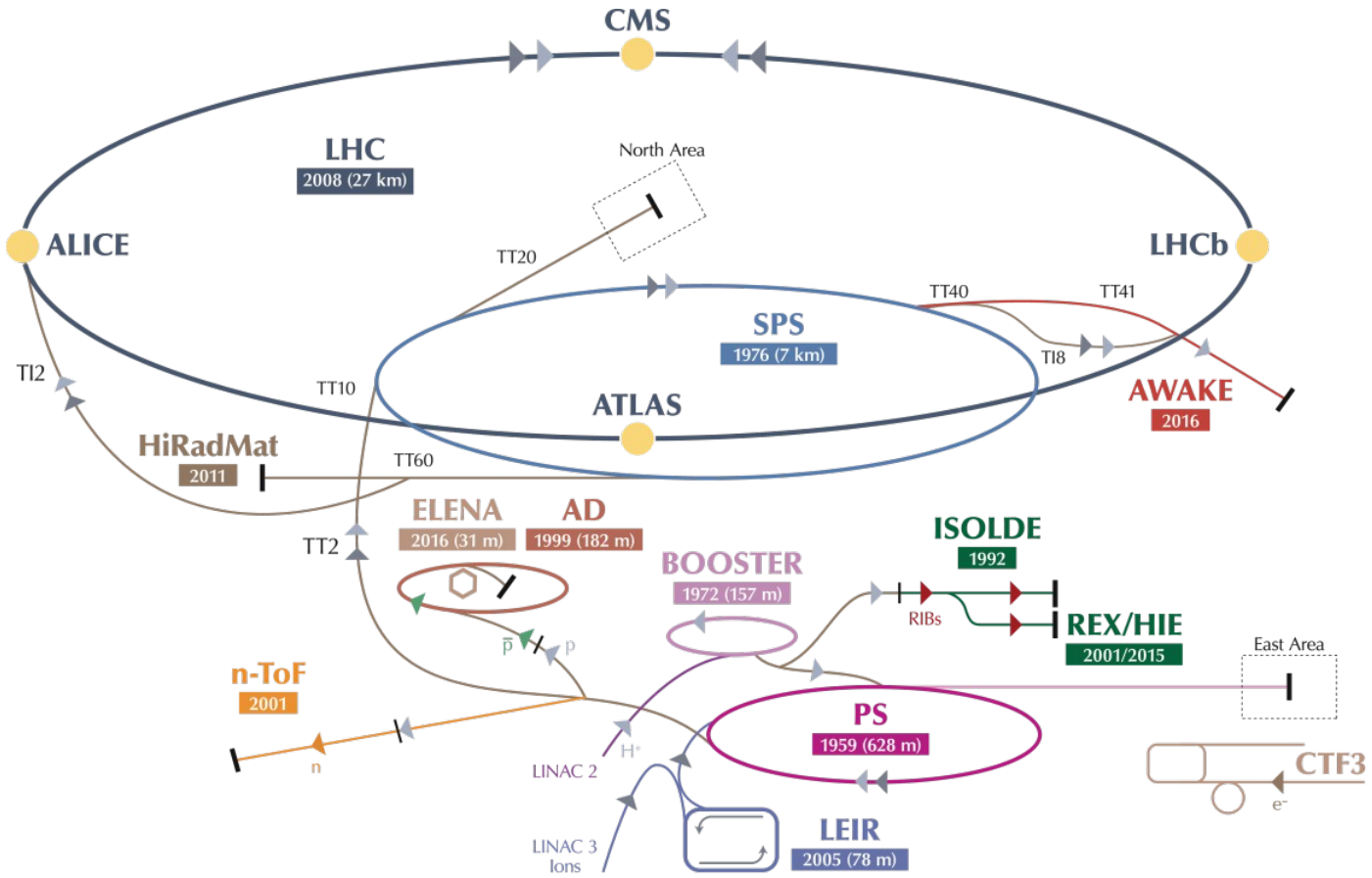
Defined as $299792458\,\mathrm{m/s}$

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

$30\,cm/ns$

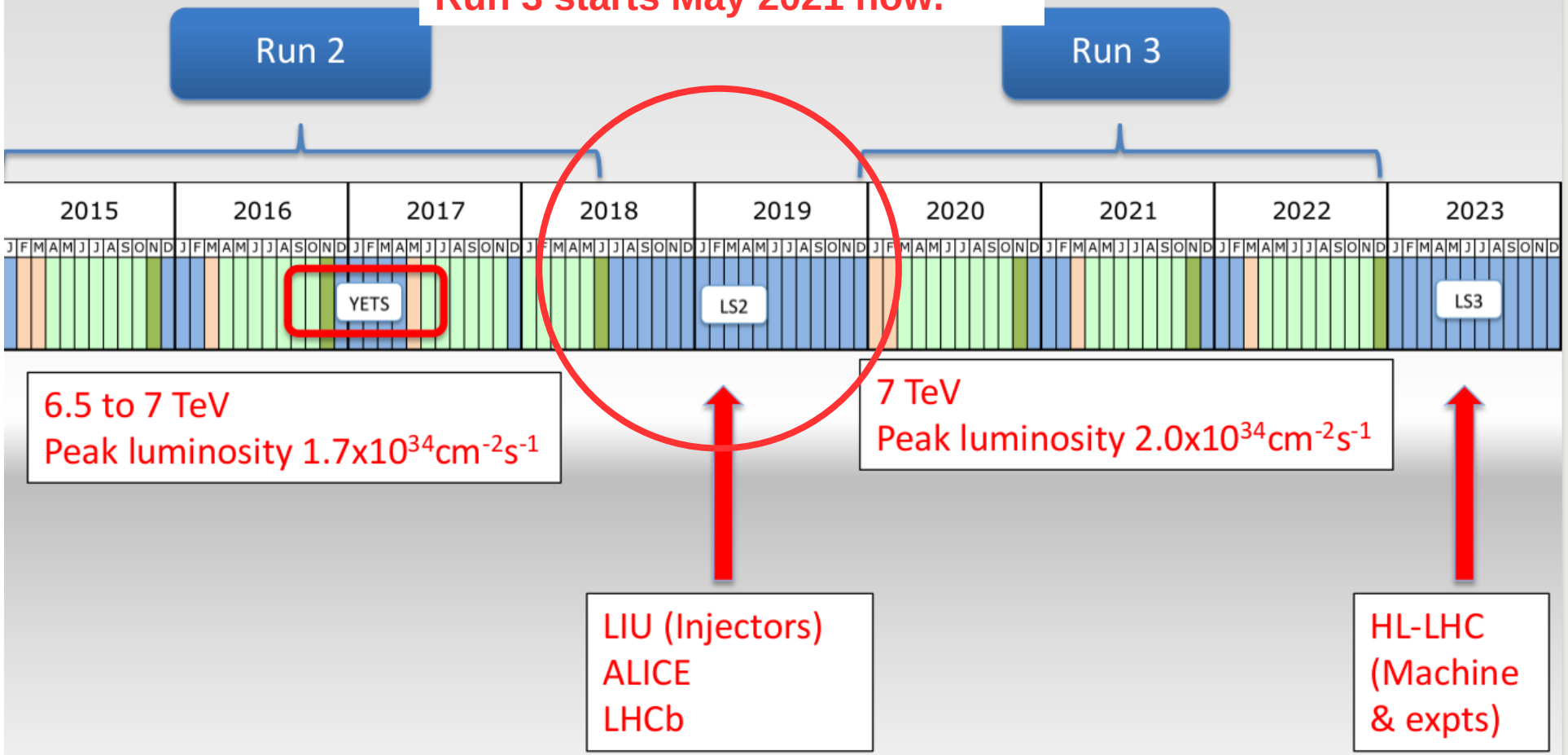
$300\,m/\mu s$ $300\,\mu m/ps$

Large Hadron Collider (LHC)



~~Next 10 years~~

***2015 Plan*: LS2 changed, starts later and takes two years; Run 3 starts May 2021 now.**



http://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-schedule-update.pdf

LIGO GraceDB Latest

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

GraceDB — Gravitational-Wave Candidate Event Database

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Latest — as of 19 June 2020 21:06:59 UTC

Test and MDC events and superevents are not included in the search results by default; see the query help for information on how to search for events and superevents in those categories.

Query:

Search for: Superevent

Search

False Alarm Rate in per sec once per year is 3.3e-8 Hz, 16 March 2020

UID	Labels	t_start	t_0	t_end	FAR (Hz)	Created (UTC)
S200316bj	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1268431093.148706	1268431094.157221	1268431095.187157	7.098e-11	2020-03-16 21:58:12 UTC
S200311bg	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1267963150.372559	1267963151.397788	1267963152.441288	8.939e-26	2020-03-11 11:59:09 UTC
S200308e	EM_READY ADVNO EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1267665584.595546	1267665585.595546	1267665586.595546	3.619e-09	2020-03-08 01:20:11 UTC
S200303ba	EM_READY PE_READY ADVNO EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK	1267272965.708772	1267272966.710855	1267272967.71948	1.316e-08	2020-03-03 12:16:14 UTC
S200302c	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1267149508.517186	1267149509.519119	1267149510.51911	9.349e-09	2020-03-02 01:58:34 UTC
S200225q	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1266645878.395508	1266645879.396484	1266645880.420007	9.186e-09	2020-02-25 06:04:44 UTC
S200224ca	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1266618171.378418	1266618172.378418	1266618173.458379	1.605e-11	2020-02-24 22:22:50 UTC
S200219ac	EM_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY GCN_PRELIM_SENT	1266140672.194824	1266140673.187400	1266140674.246774	1.330e-08	2020-02-19 10:28:27 UTC
S200213t	EM_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1265602257.327981	1265602258.327981	1265602259.327971	1.767e-08	2020-02-13 04:11:05 UTC
S200208q	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1265202094.944824	1265202095.991118	1265202096.991118	2.518e-09	2020-02-08 13:01:39 UTC
S200129m	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1264316115.411621	1264316116.435104	1264316117.460934	6.697e-32	2020-01-29 06:55:42 UTC
S200128d	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1264213228.897043	1264213229.903320	1264213230.953959	1.647e-08	2020-01-28 02:20:36 UTC
S200116ah	EM_READY PE_READY ADVNO EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1263211019.170712	1263211020.170712	1263211021.170772	2.029e-12	2020-01-16 11:57:11 UTC
S200115j	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1263097406.735840	1263097407.752869	1263097408.769033	2.094e-11	2020-01-15 04:23:40 UTC
S200114f	EM_READY ADVOK EM_Selected SKYMAP_READY DQOK GCN_PRELIM_SENT	1263002916.225766	1263002916.239300	1263002916.252855	1.226e-09	2020-01-14 02:11:12 UTC
S200112r	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1262879935.091777	1262879936.093931	1262879937.093971	1.283e-11	2020-01-12 15:59:06 UTC
S200108v	EM_READY PE_READY ADVNO EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1262512855.558755	1262512856.558755	1262512857.558755	2.669e-13	2020-01-08 10:01:07 UTC
S200106av	EM_READY ADVNO EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1262370880.578613	1262370881.578613	1262370882.623047	3.128e-08	2020-01-06 18:36:27 UTC
S200106au	EM_READY ADVNO EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1262370886.292480	1262370887.292480	1262370888.456543	3.661e-09	2020-01-06 18:35:21 UTC
S200105ae	EM_READY PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1262276683.057208	1262276684.057208	1262276685.059117	7.672e-07	2020-01-05 16:24:53 UTC
S191225aq	EM_READY ADVNO EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1261346252.856445	1261346253.870117	1261346254.870117	1.267e-08	2019-12-25 21:57:52 UTC
S191222n	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1261020954.112305	1261020955.119478	1261020956.127930	6.459e-12	2019-12-22 03:35:58 UTC
S191220af	EM_READY PE_READY ADVNO EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1260879871.690032	1260879872.690032	1260879873.690394	3.963e-10	2019-12-20 12:24:45 UTC

LIGO GraceDB Latest – S190521r

- FAR 1/146yrs https://gracedb.ligo.org/superevents/S200316bj/view/

GraceDB — Gravitational-Wave Candidate Event Database

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Superevent Info

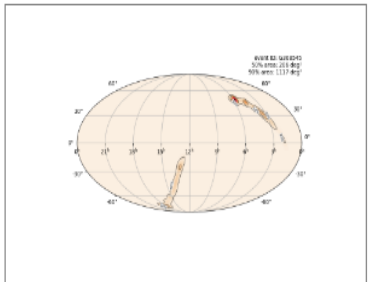
Superevent ID	Category	Labels	FAR (Hz)	FAR (yr^{-1})	t_start	
S200316bj	Production	EM_READY PE_READY ADVOK EM_Selected SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	7.098e-11	1 per 446.44 years	1268431093.148706	1268431

Preferred Event Info

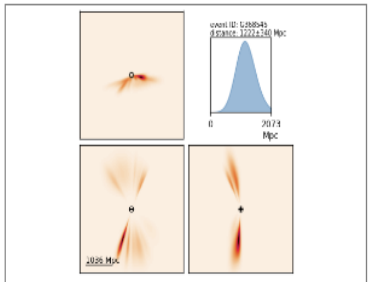
Group	Pipeline	Search	Instruments	GPS Time Event time	
CBC	gstlal	AllSky	H1,L1,V1	1268431094.1572	2020-03-16 21:58:26 U

Superevent Log Messages

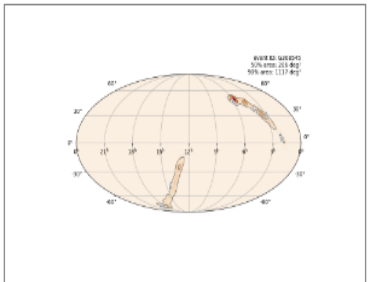
Sky Localization



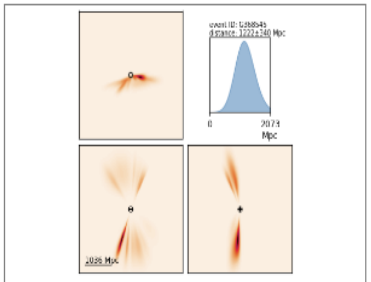
Mollweide projection of bayestar.fits.gz bayestar.png. Submitted by LIGO/Virgo EM Follow-Up on Mar 16, 2020 22:00:42 UTC



Volume rendering of bayestar.fits.gz bayestar.volume.png. Submitted by LIGO/Virgo EM Follow-Up on Mar 16, 2020 22:01:23 UTC



Mollweide projection of bayestar.fits.gz bayestar.png. Submitted by LIGO/Virgo EM Follow-Up on Mar 16, 2020 22:06:53 UTC



Volume rendering of bayestar.fits.gz bayestar.volume.png. Submitted by LIGO/Virgo EM Follow-Up on Mar 16, 2020 22:07:29 UTC

LIGO GraceDB Latest – S190521r