LIGO-Virgo Collaboration

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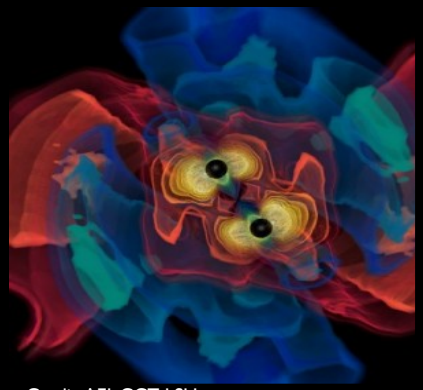
Why I am giving this talk

- I am not a member of either LIGO or Virgo.
- Unfortunately, we chose the date of HOW 2019 to coincide with the LIGO-Virgo Collaboration Meeting.
- Am thus giving this talk on behalf of Peter Couvares who helped me put these slides together.
  - All useful information is from him.
  - All mistakes are mine.

The Science

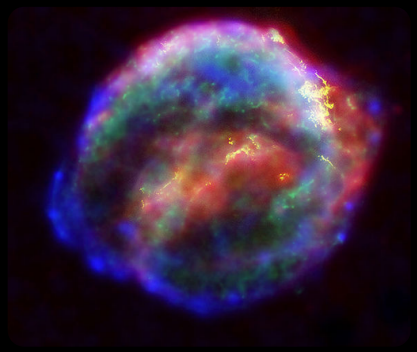
Gravitational Wave Astrophysics



Credit: AEI, CCT, LSU

Coalescing Binary Systems

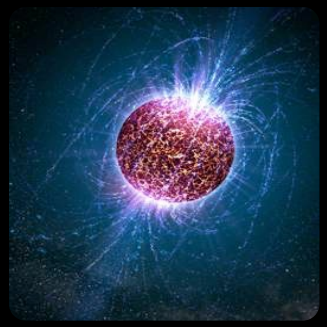
Neutron Stars,
Black Holes



Credit: Chandra X-ray Observatory

'Bursts'

Core collapse supernovae
Cosmic strings
Unknown

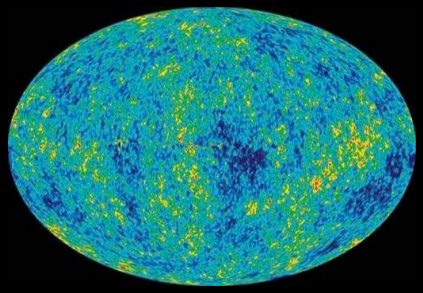


Casey Reed, Penn State

Continuous Sources

Spinning neutron stars

crustal deformations, accretion



NASA/WMAP Science Team

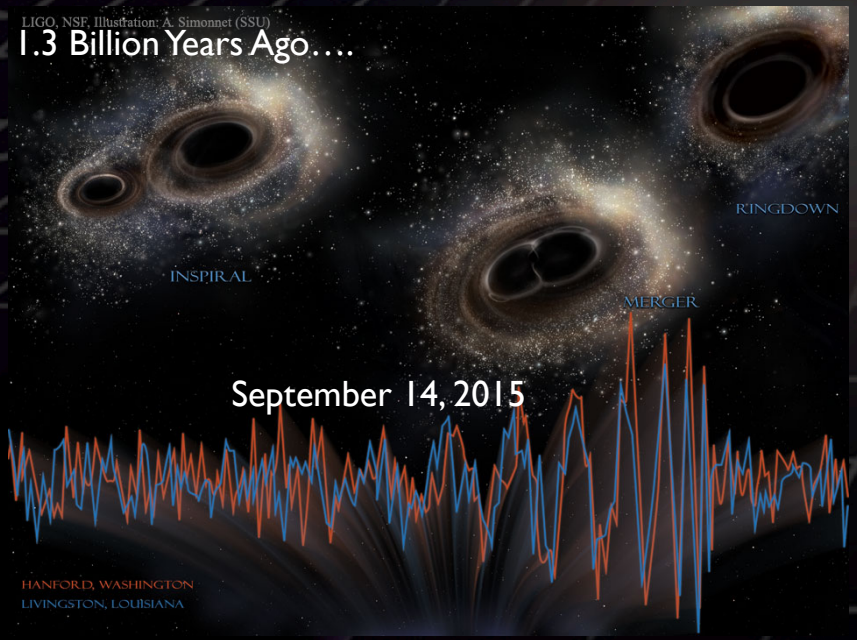
Stochastic GW background

cosmological or astrophysical

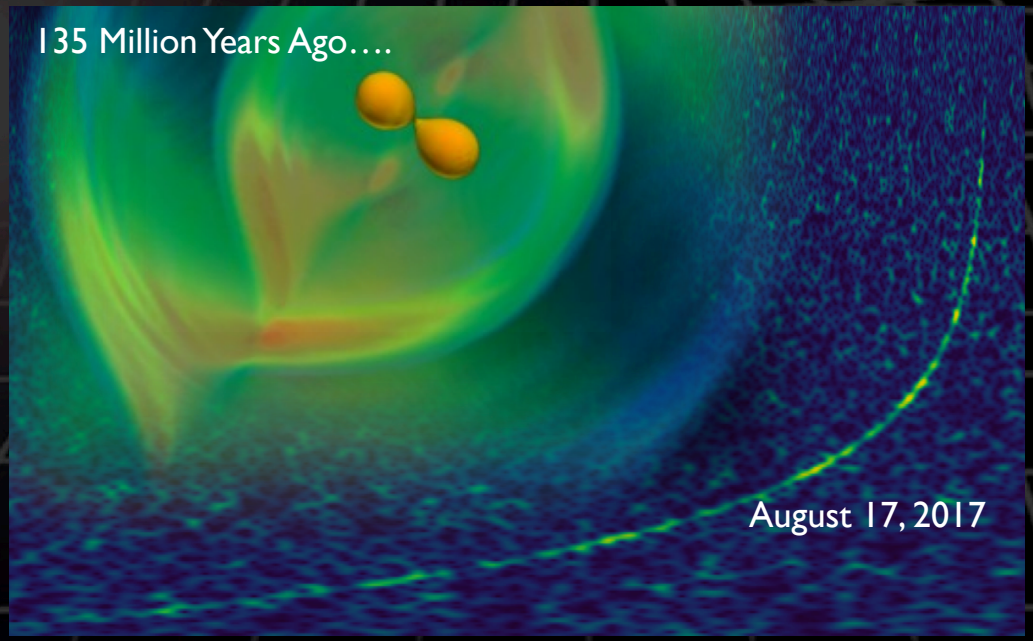
Broadly speaking, 4 different types of wave phenomena are searched for.

Coalescing Binary Detections

GW150914 and GW170817:
Two ground-breaking discoveries that opened a new era in Gravitational Wave Astronomy



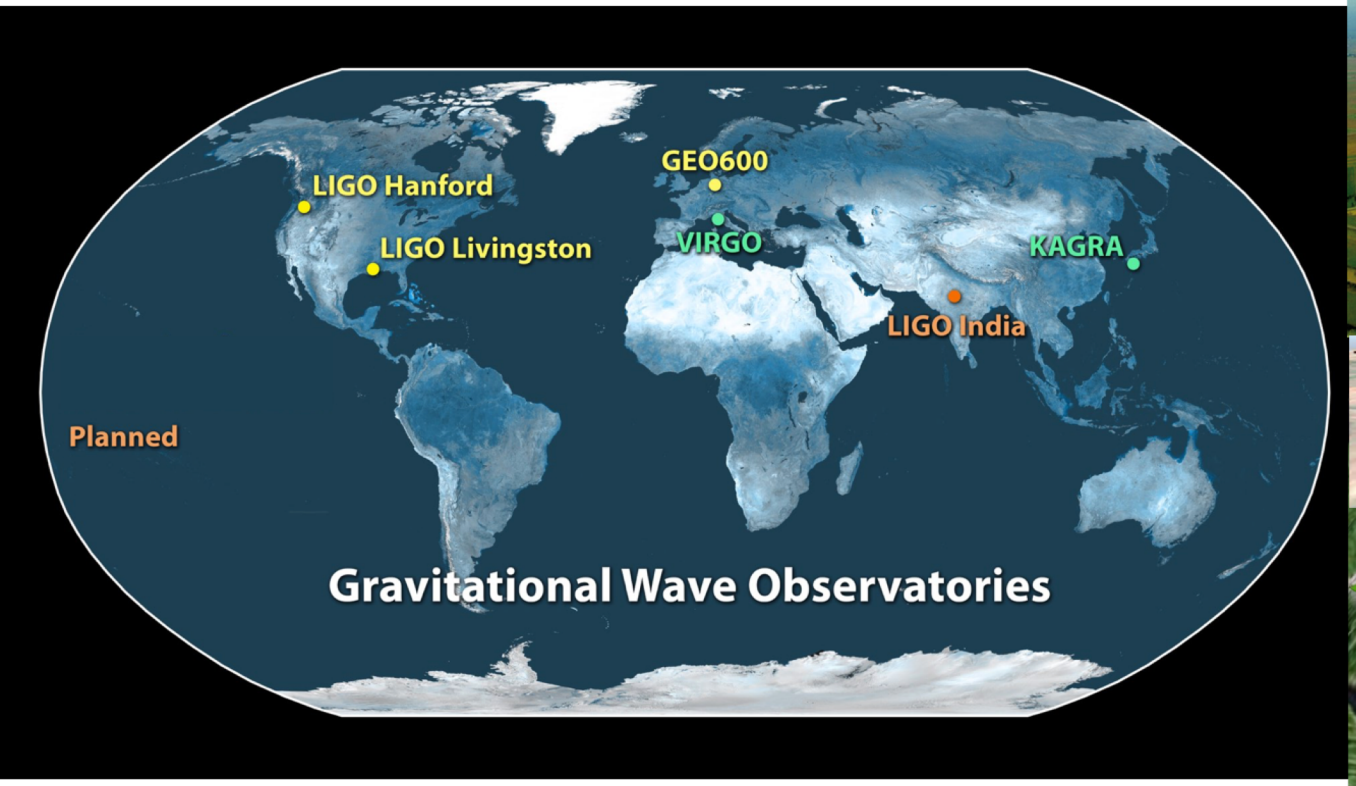
Binary Black Hole Coalescence



Binary Neutron Star Coalescence

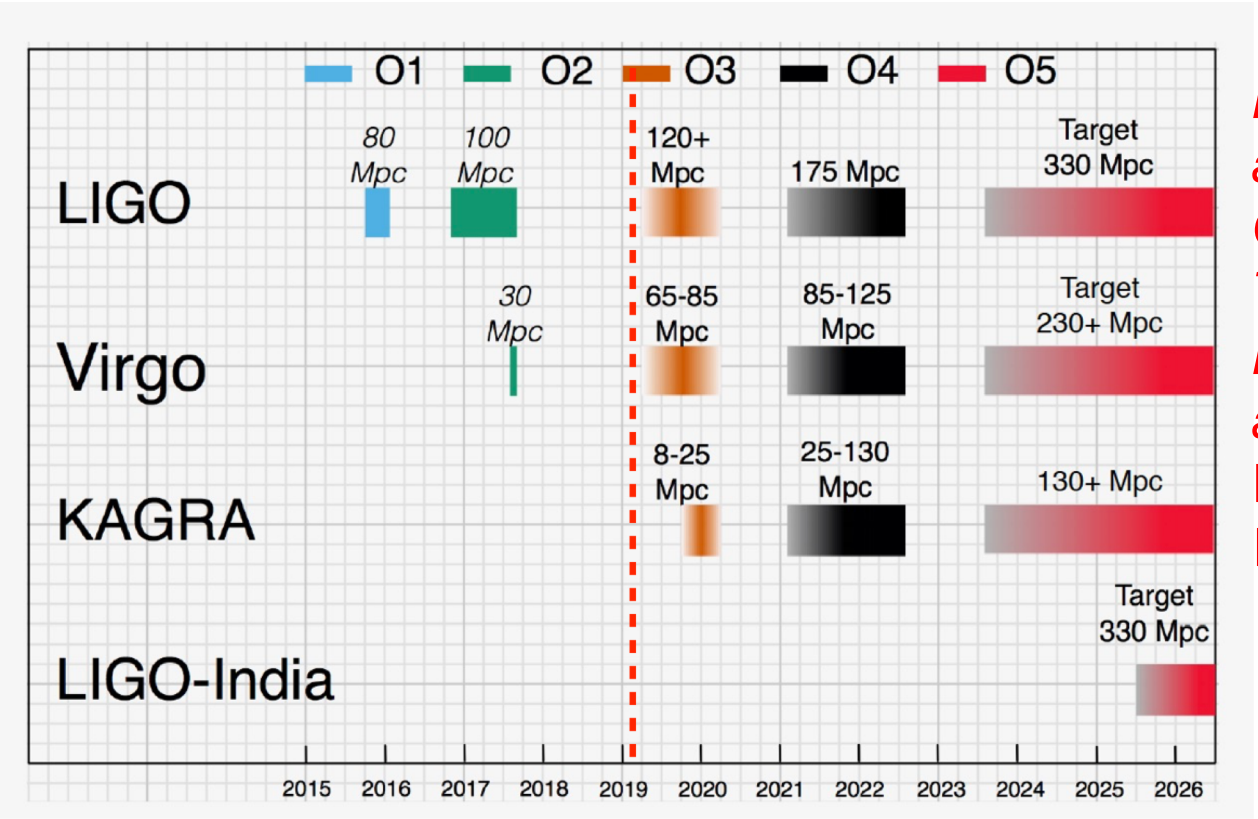
Both come from just one of the 4 signatures that are being searched for.

Multiple Instruments Working Together



A Global Quest

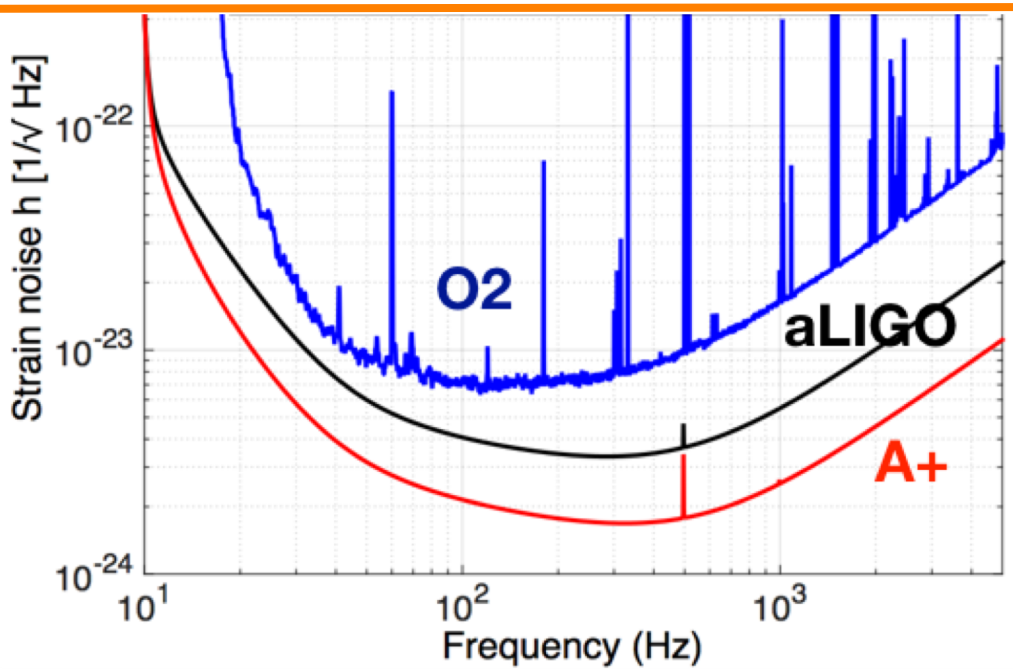
Near Term Observing Plan



Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo and KAGRA — https://dcc.ligo.org/LIGO-P1200087/public

Number of detected compact binary mergers ~ R^3

Evolution of Strain Sensitivity

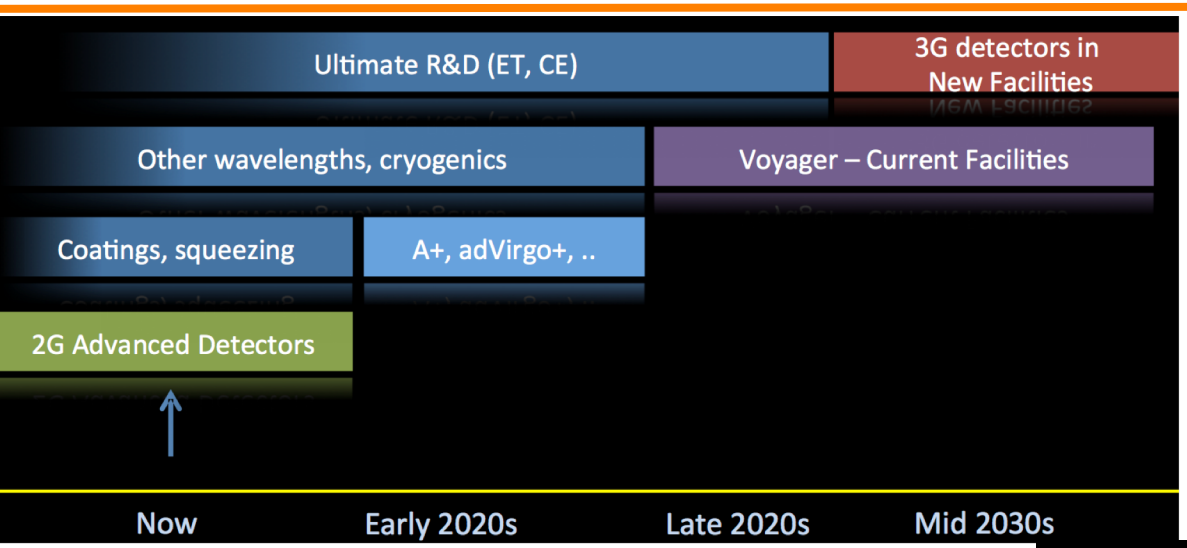


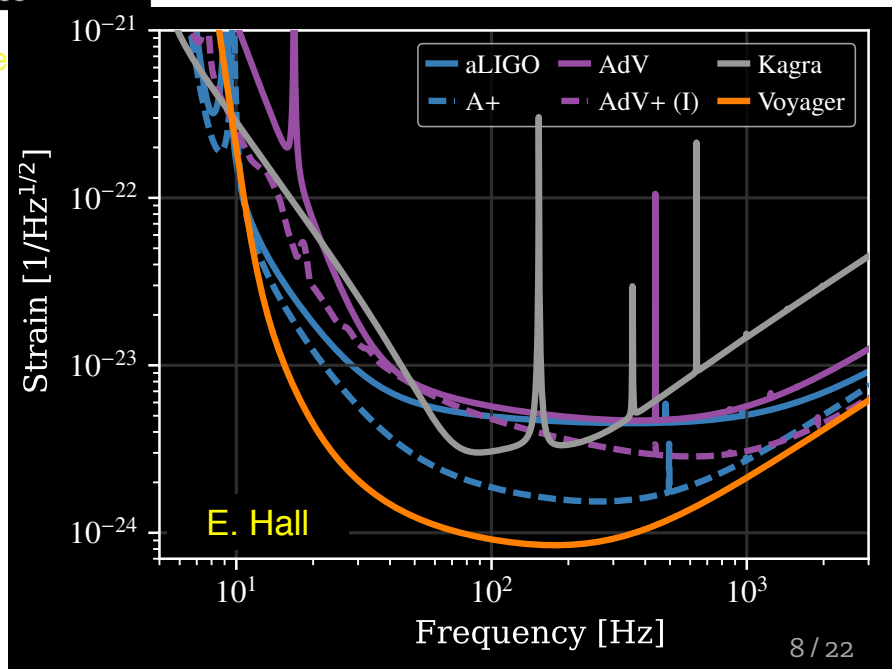
~ 10^2 binary coalescence per year (2021)

~ 10^3 binary coalescence per year (~2024)

Rapid Reduction of Strain Noise within the next few years leads to massive increase in detections because of R^3.

Longer Term Roadmap





Voyager ~ 10^4 binary coalescence/year

Multiple 3rd Generation Approaches

The 3rd Generation

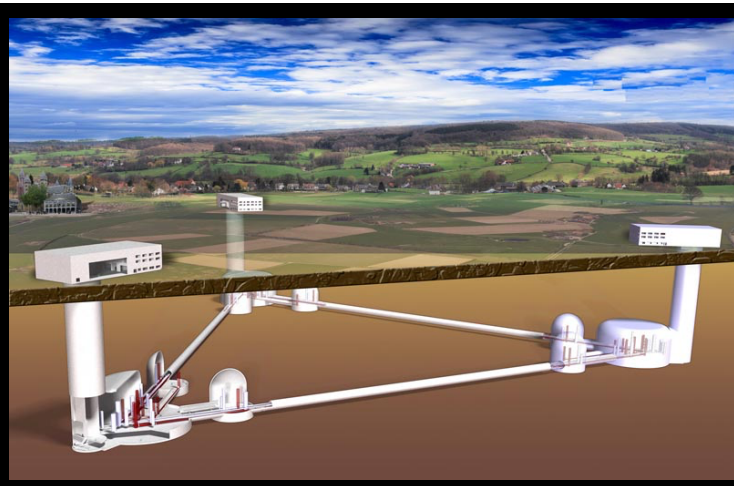
~10^5 binary coalescences per year (2030s)

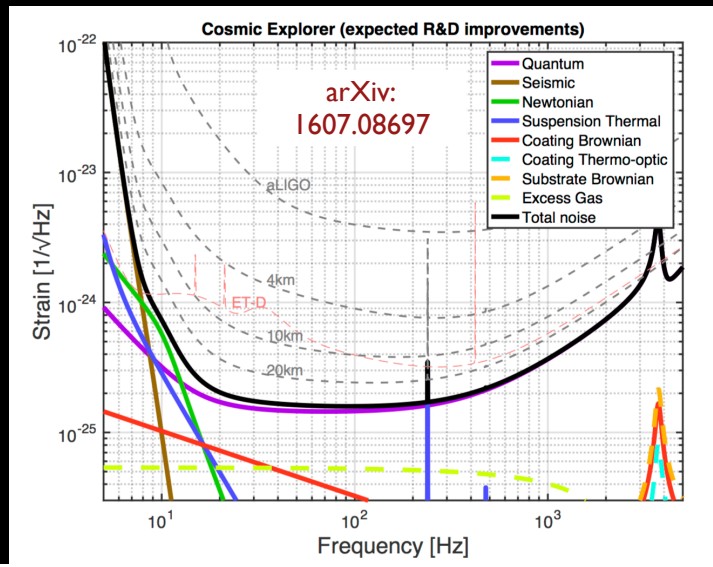
Einstein Telescope

- European conceptual design study
- Multiple instruments in xylophone configuration
- underground to reduce newtonian background
- 10 km arm length, in triangle.
- Assumes 10-15 year technology development.

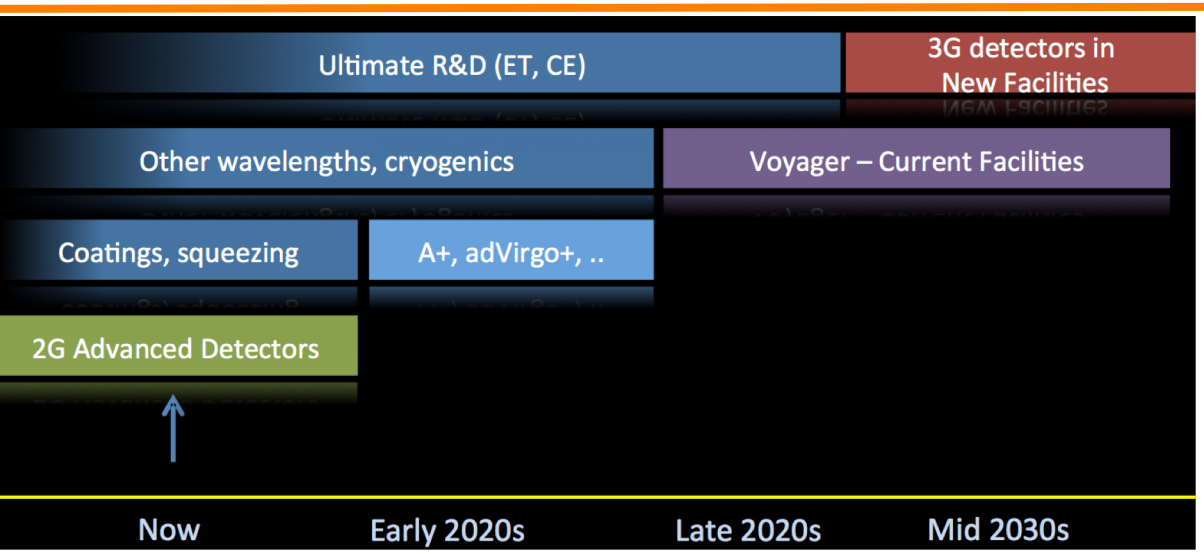
Cosmic Explorer

- NSF-funded US conceptual design study starting now
- 40km surface Observatory baseline
- Signal grows with length – not most noise sources
- Thermal noise, radiation pressure, seismic, Newtonian unchanged; coating thermal noise improves faster than linearly with length



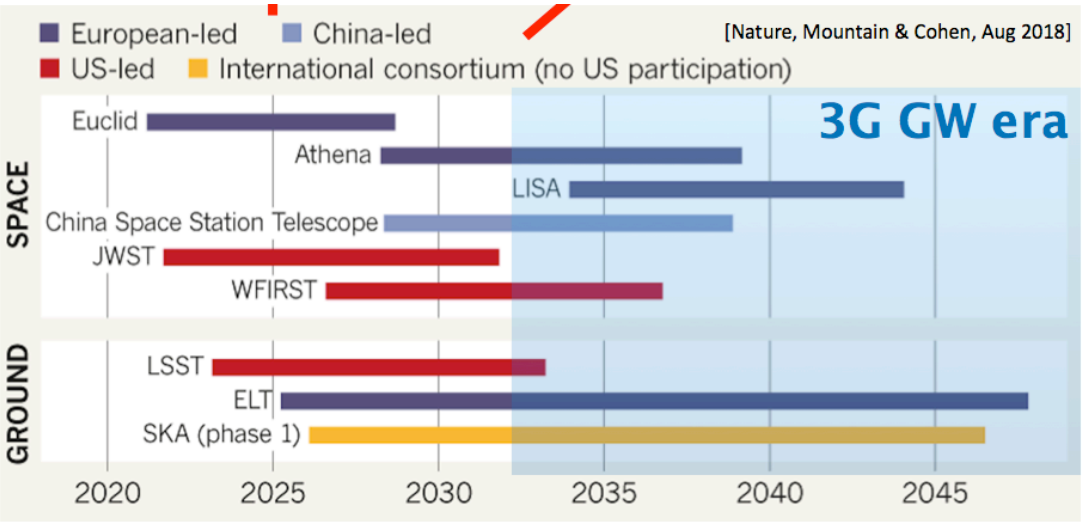


Multi-messenger Astrophysics



Many powerful instruments online concurrently

Credit: L. Barsotti



Computing

Ligo-Virgo Computing

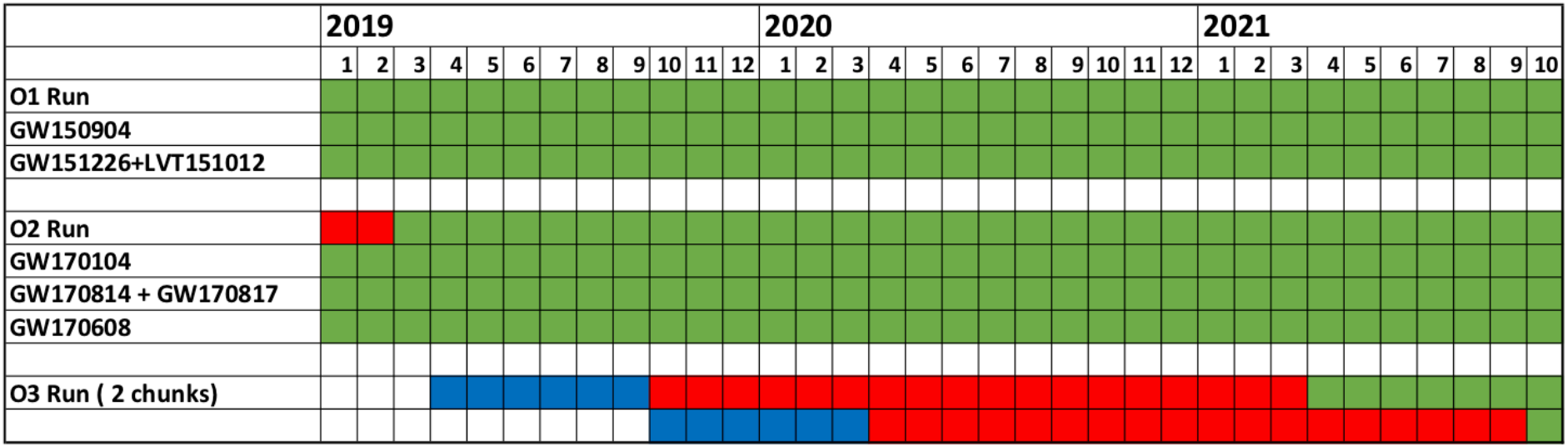
Compute:

- For the third observing run (O3), the LVC expects to need ~500 million CPU core-hours of data analysis for ~80 astrophysical searches, followup activities, and detector characterization.
- The 10 most demanding of these 80 analyses comprise ~90% of the demand.
- Most of this computing is "pleasingly parallel" High Throughput Computing (HTC) for "deep" offline searches; ~10% is low-latency data analysis needed to generate rapid alerts (OPA)
- Currently ~90% provided by dedicated LIGO-Virgo clusters vs. ~10% from external shared computing resources — but growth of the dedicated resources has flattened while shared component is growing.
- Growing shared, external computing resources are presenting new distributed computing and data access challenges. GPU has been the most successful and cost-effective: deploying at scale for the first time in O3.
- Currently no cloud usage; no major technical obstacles, but logistics are unclear.

Data:

- LIGO h(t) strain data is O(10TB) per IFO per observing year.
- LIGO raw data (all channels, full sample rate) is O(1PB) per IFO per observing year.
- No longer "big data" by 2018 standards — but non-trivial in a distributed HTC environment.

Commitment to Open Data

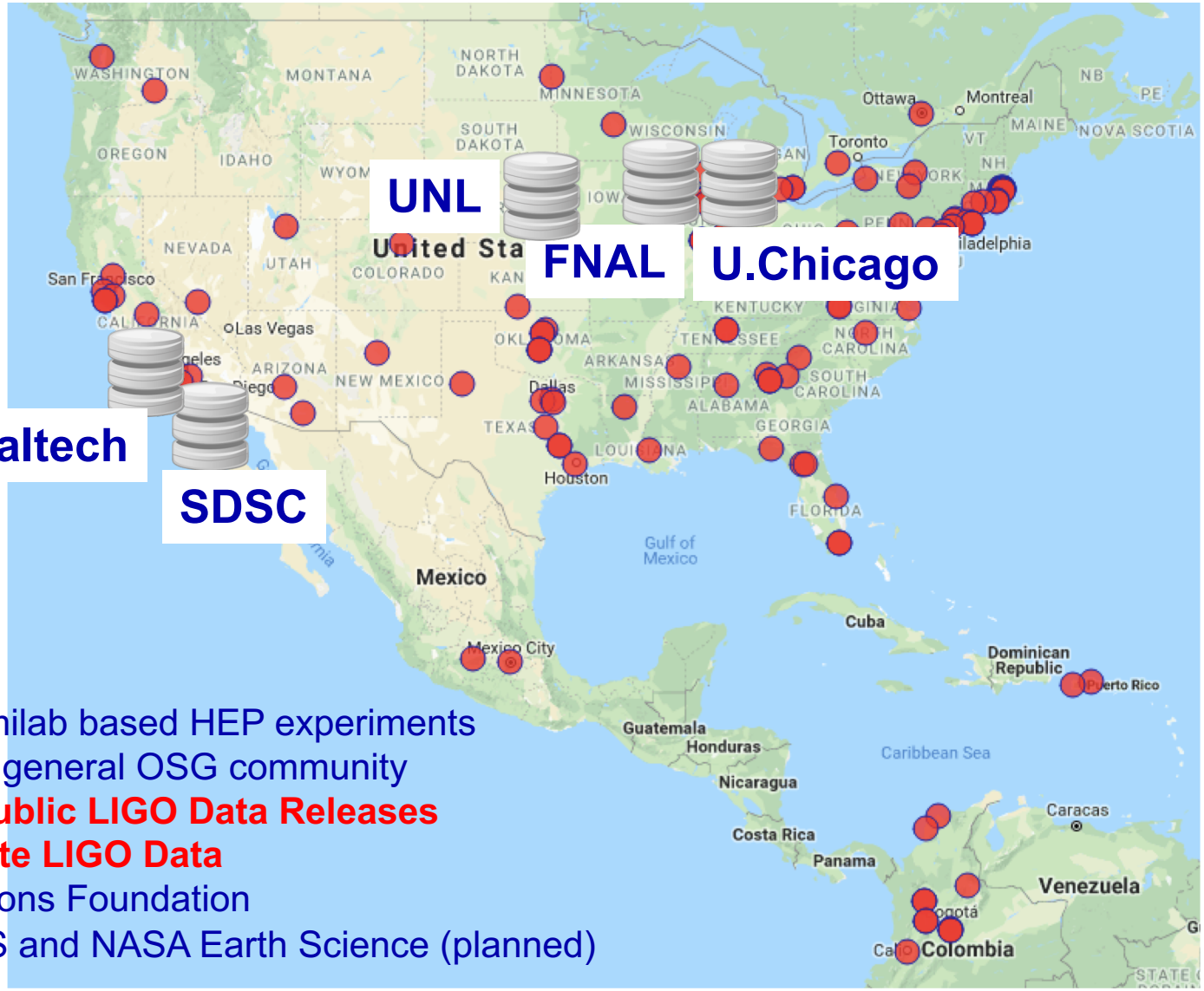


Data Acquisition
1.5 year proprietary period (as specified in the LIGO Data Management Plan)
Open data

See talk by Duncan Brown on use of this Open Data. (Wednesday 15:00 OSG-AHM Session)

Also, starting with O3: Open Public Alerts.
https://www.ligo.org/scientists/GWEMalerts.php

LIGO-Virgo use the OSG Data Federation based on Xrootd/cvmfs



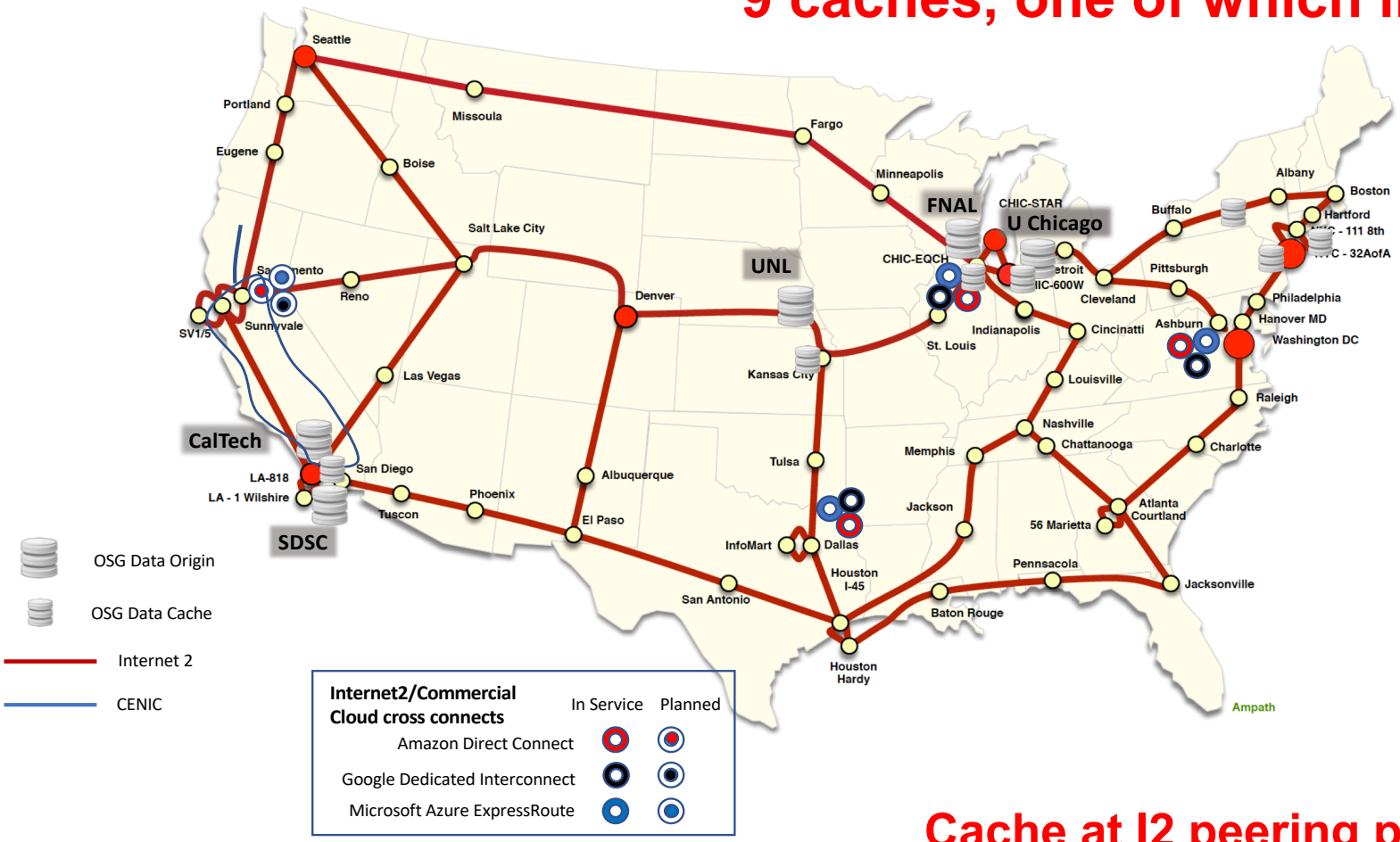
FNAL: Fermilab based HEP experiments
U.Chicago: general OSG community
Caltech: Public LIGO Data Releases
UNL: Private LIGO Data
SDSC: Simons Foundation
NCSA: DES and NASA Earth Science (planned)

Caches in network & at endpoints

Open Science Grid

UCSD

9 caches, one of which in EU



Amsterdam

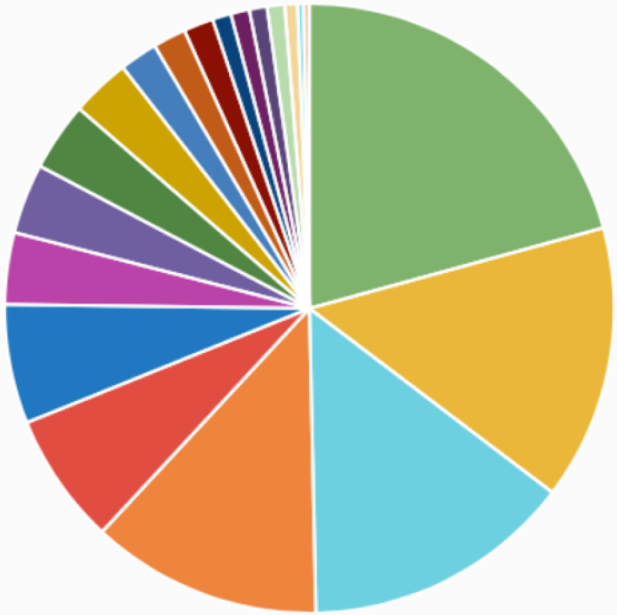
Cache at I2 peering point with Cloud providers in Chicago

Last 30 days

	Directory	Bytes
	/pnfs/fnal.gov/usr/dune	390.114TB
GW public Data O1	/gwdata/O1	180.208TB
	/pnfs/fnal.gov/usr/minerva	99.352TB
	/pnfs/fnal.gov/usr/des	63.204TB
GW private Data	/user/ligo	58.211TB
	....	
GW public Data O2	/gwdata/O2	3.163TB

GW O1 Data second most popular in last 30 days
GW O2 Data only recently become public.

A case for caching



	total
UCSDT2	520 K
SURFsara	365 K
IN2P3-CC	359 K
NIKHEF-ELPROD	307 K
Comet	175 K
GPGrid	158 K
INFN-T1	95.1 K
SU-ITS-CE2	93.2 K
SU-ITS-CE3	91.2 K
Georgia_Tech_PACE_CE_1	78.6 K
GLOW	50.4 K
AGLT2	43.9 K
LIGO-CIT-CE	39.6 K
PL_CAMK-CYFRONET	24.8 K
BNL-ATLAS	24.7 K
MWT2	23.5 K
LIGO-WA-CE	23.3 K
NWICG_NDCMS	16.8 K
RAL-LCG2	7.97 K
Tusker	7.84 K

Top 20 core-hour contributors to LIGO-Virgo via OSG within last year.

1/3 of it coming from WLCG T1 in EU SURFSara, IN2P3, NIKHEF, INFN, RAL

The LIGO workflow reuses each file O(100) times.
Total data is only few TB but we moved many petabytes worth out of UNL before LIGO started using the caches in OSG.

Cache in Amsterdam is effective way to reduce transatlantic network traffic.

Need for Middleware & Infrastructure Coordination

- As the gravitational wave community has become a global enterprise using WLCG resources via OSG and EGI middleware we need better coordination:
  - Issues with recognition of certificate authorities
    - CA bundles from OSG and EGI are not identical. The CA that is used by LIGO users is not in EGI bundle.
  - Issues with network routing from WLCG to cache at University of Amsterdam
    - E.g. IN2P3 – NYC – University of Amsterdam
- Concerned of hitting other problems in the future unless we make an effort to include LIGO-Virgo needs in existing coordination via WLCG.

Summary & Conclusion

- **LIGO-Virgo Collaboration has rapidly expanding science program on WLCG resources.**
  - Supporting private and public data.
- Roughly x1000 increase in coalescent binary detections/year expected within the next couple decades.
- Additional interferometers coming online.
- Desire for existing coordination between OSG & EGI within WLCG to include focus on GW community needs.