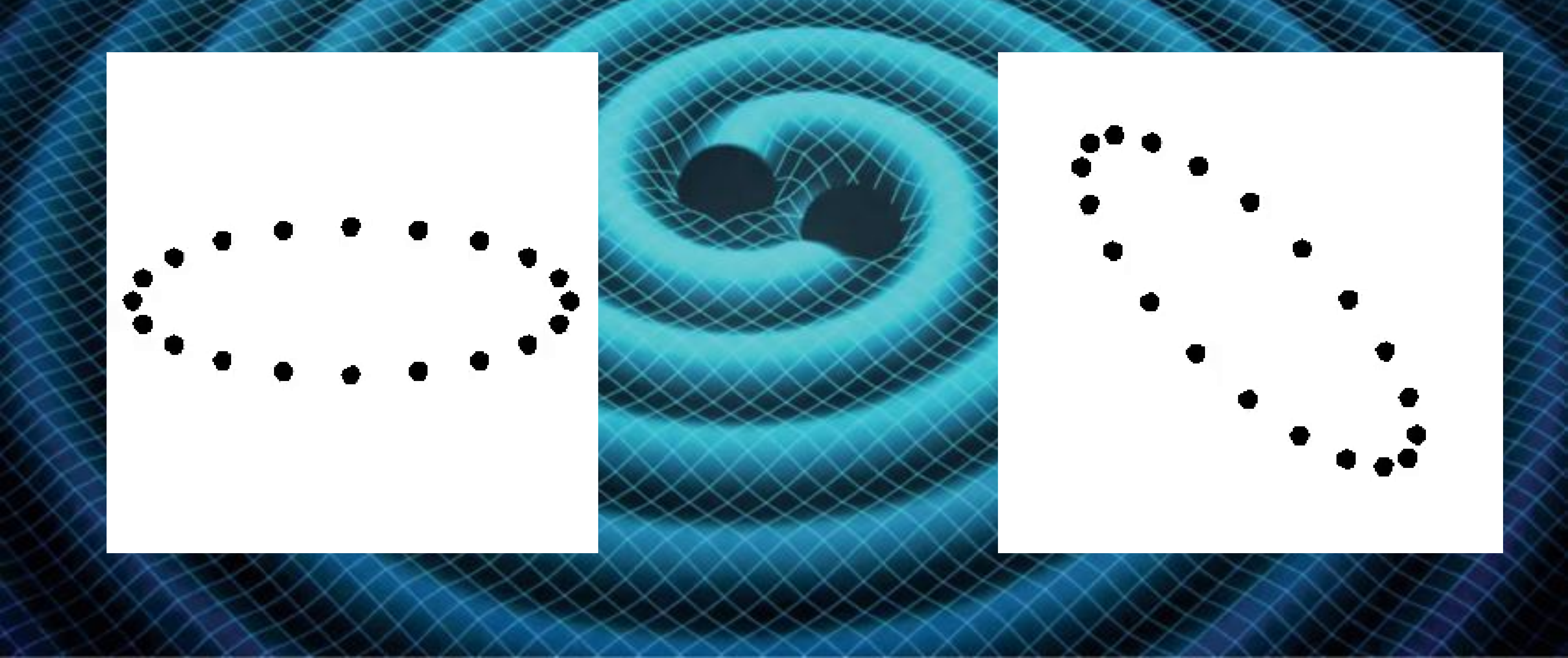
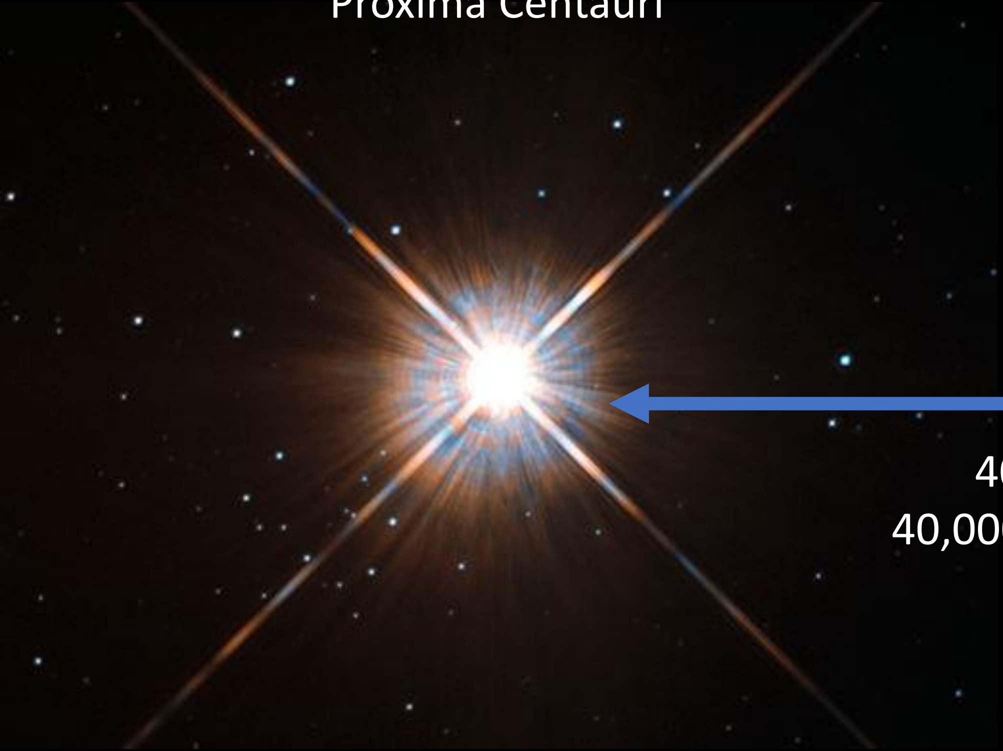
Advanced LIGO computing requirements

Stephen Fairhurst
& Paul Hopkins

Accelerating Mass produces Gravitational Waves

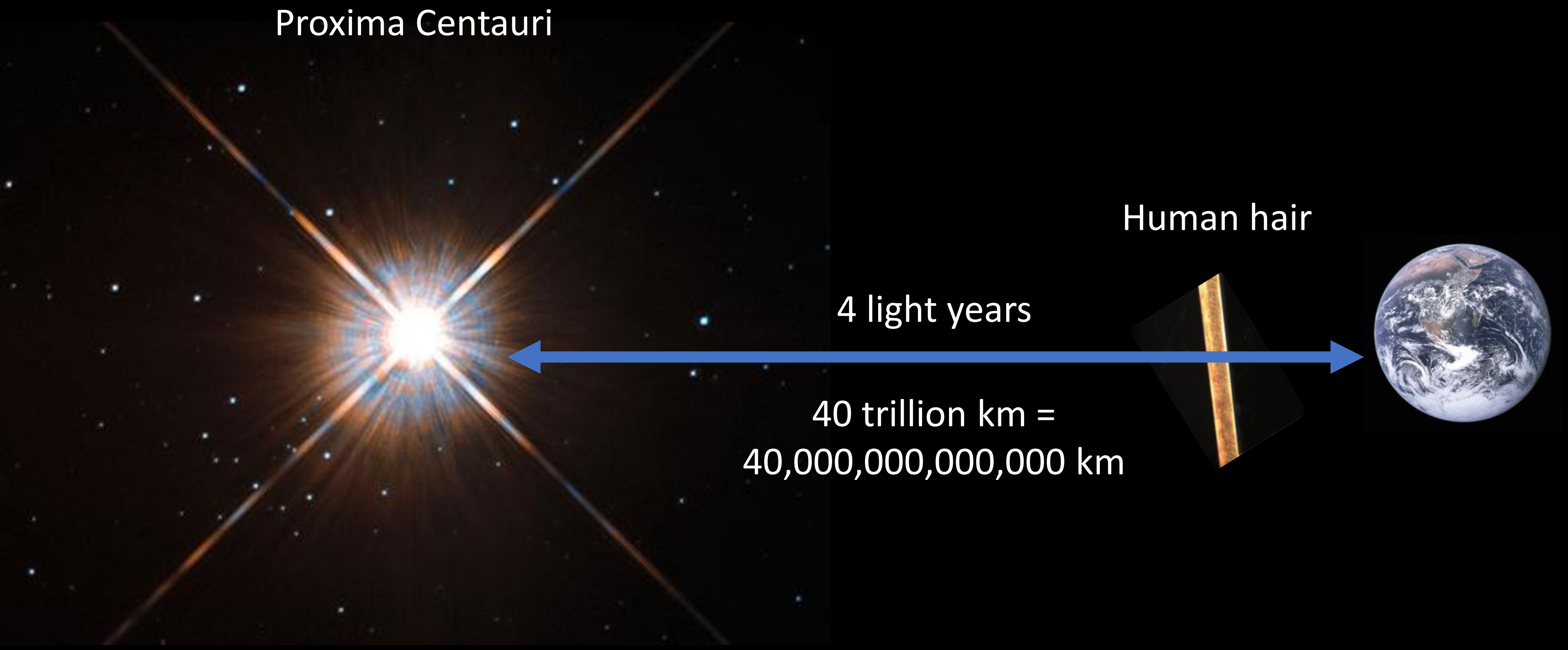


Proxima Centauri



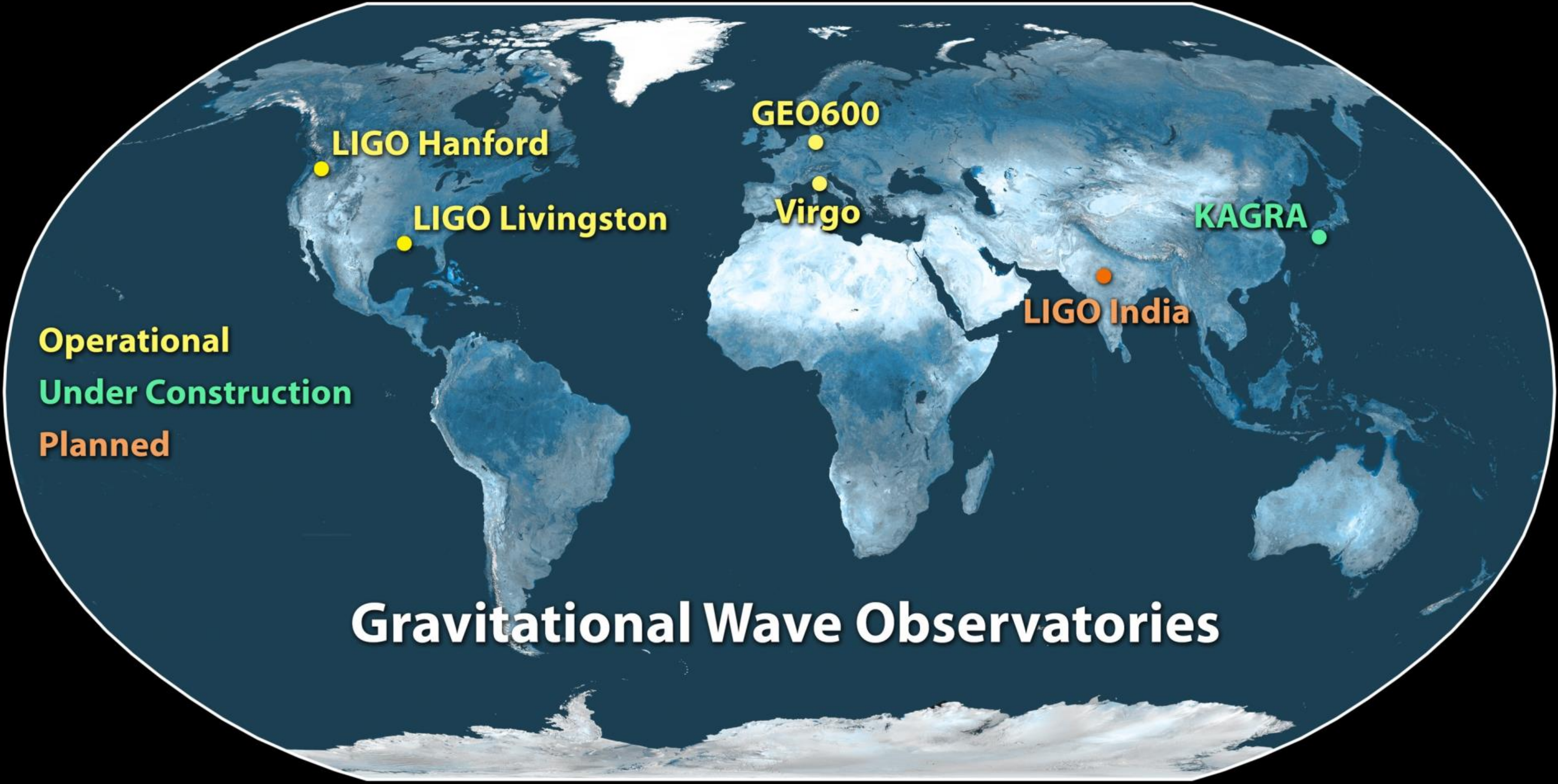
4 light years

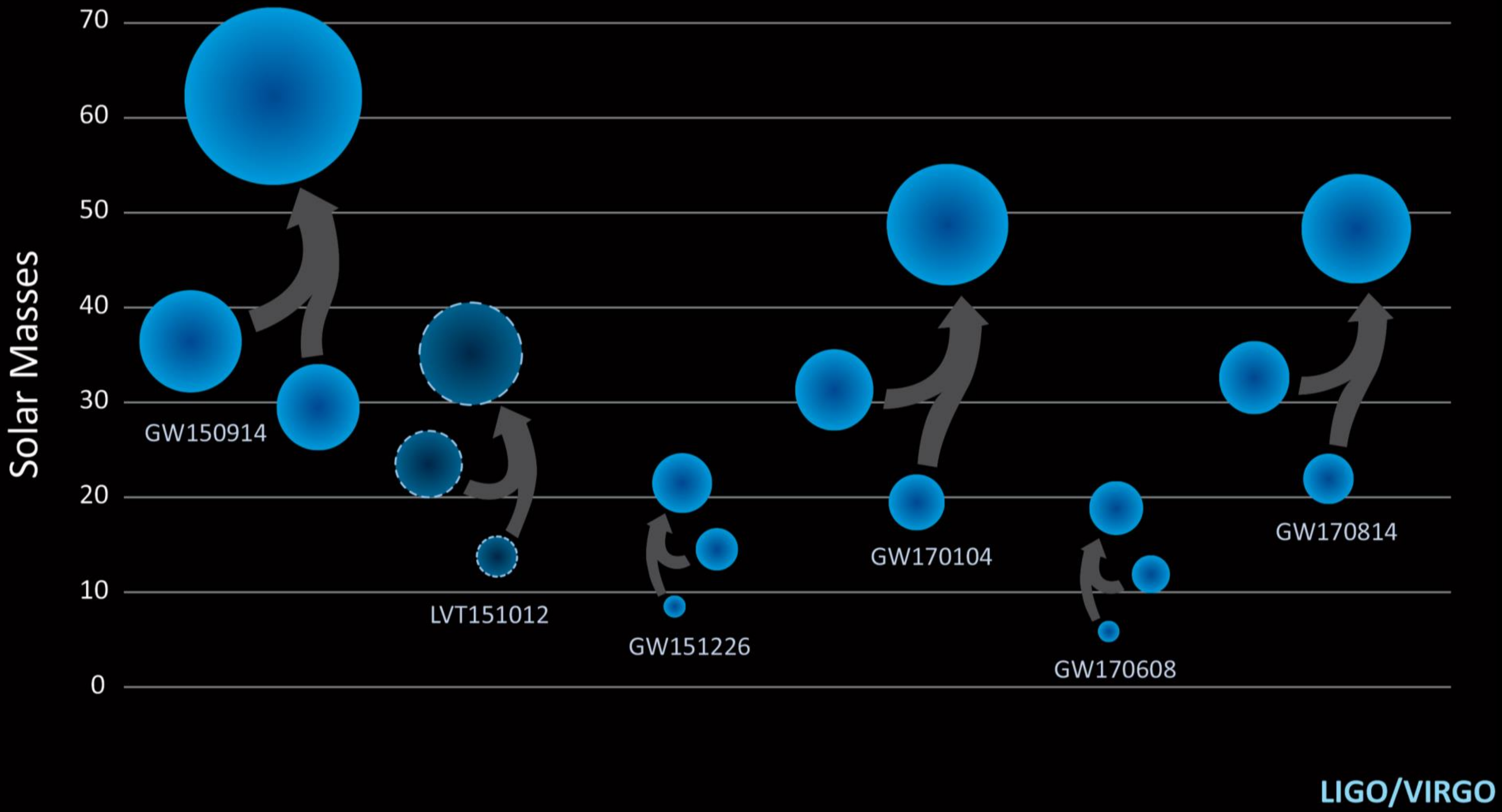
40 trillion km =
40,000,000,000,000 km

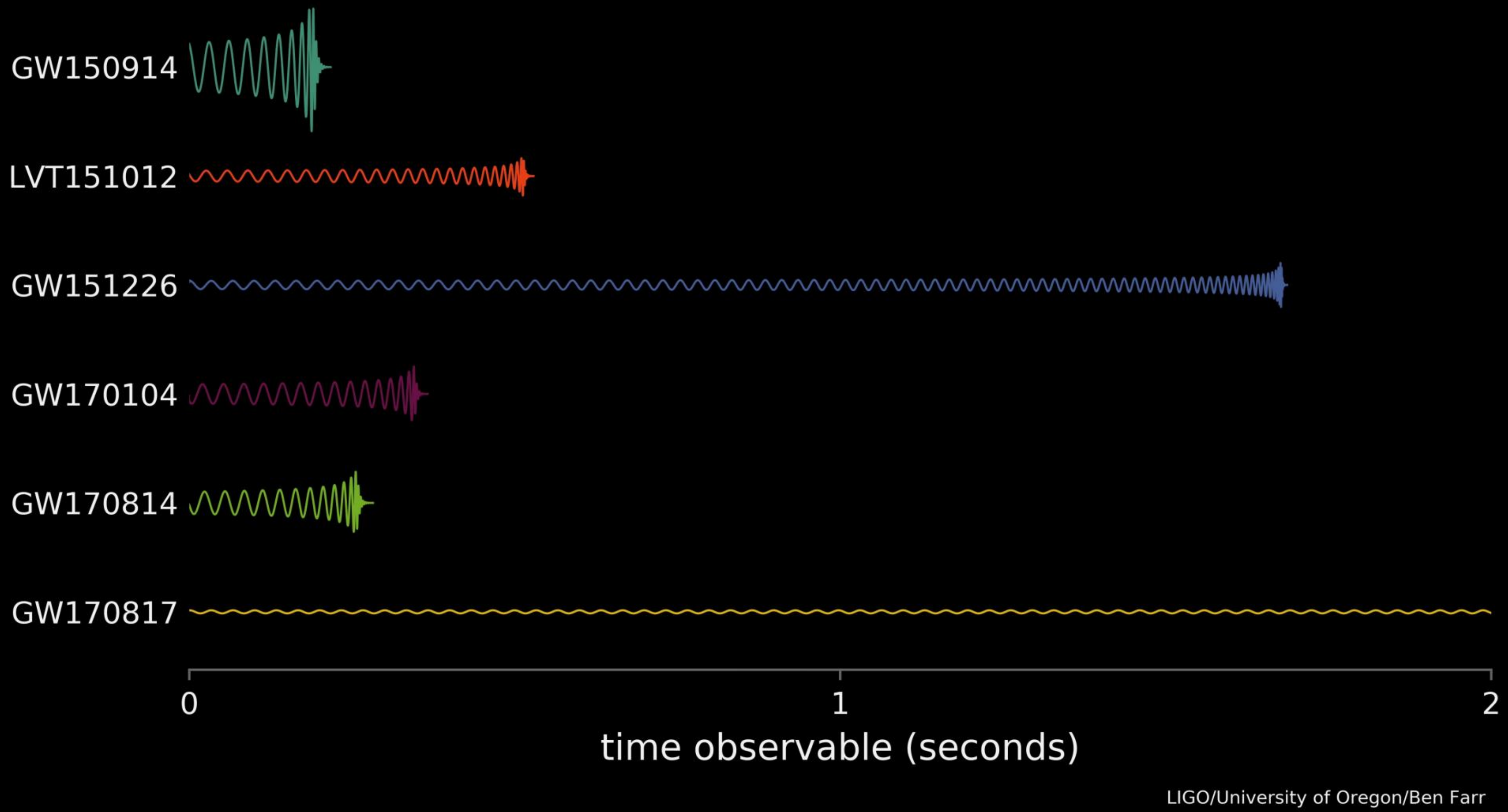


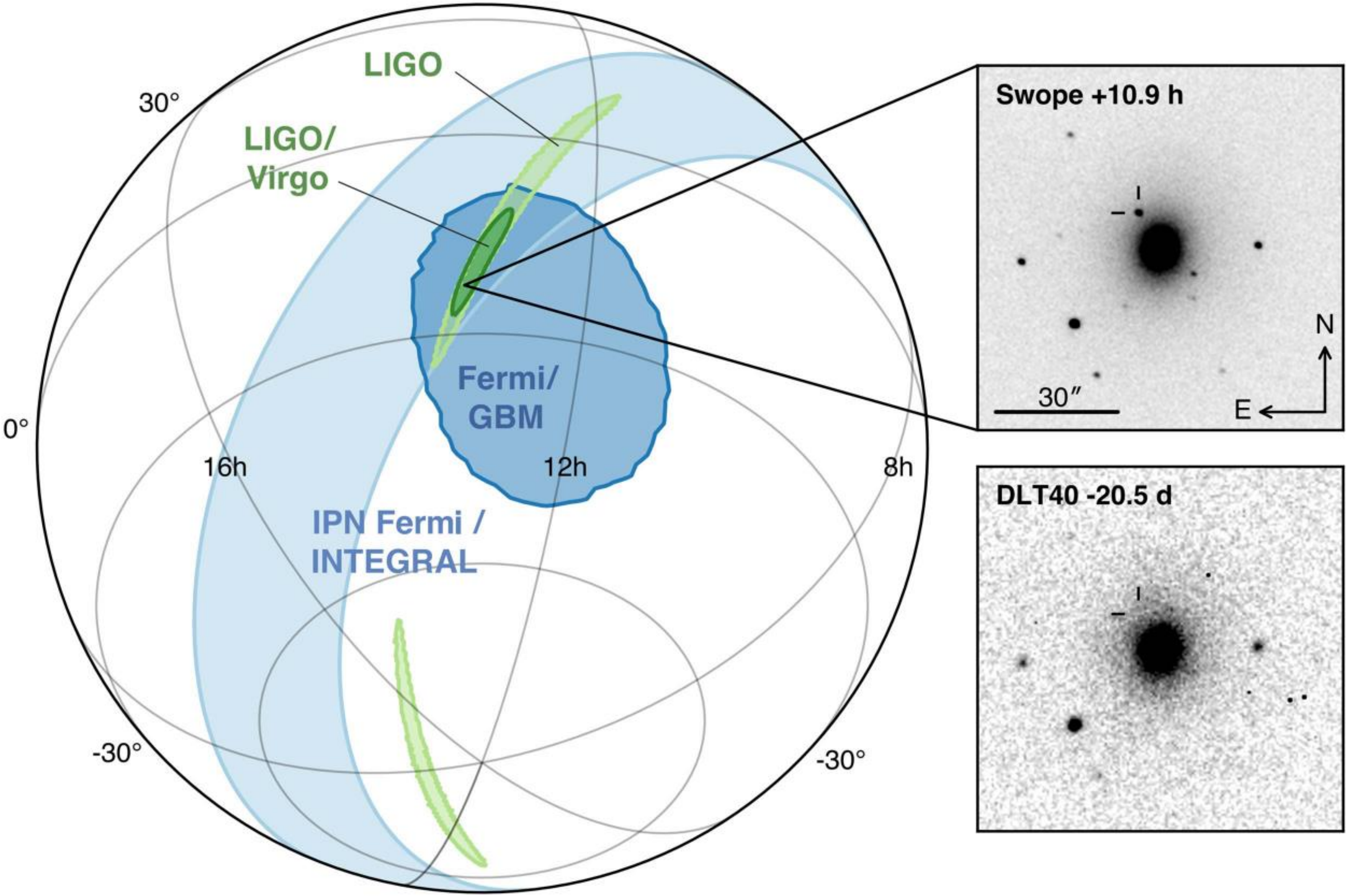
WARNING: Not to scale!


LIGO Hanford Observatory
LIGO Hanford
LIGO Livingston


GEO600
LIGO Hanford
Virgo
LIGO Livingston
KAGRA
LIGO India
Operational
Under Construction
Planned
Gravitational Wave Observatories

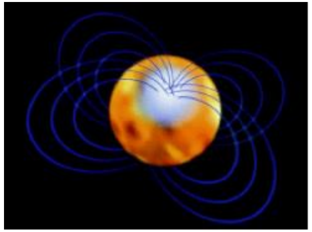

Solar Masses
70
60
50
40
30
20
10
0
GW150914
LVT151012
GW151226
GW170104
GW170608
GW170814
LIGO/VIRGO


GW150914
LVT151012
GW151226
GW170104
GW170814
GW170817
0
1
2
time observable (seconds)
LIGO/University of Oregon/Ben Farr

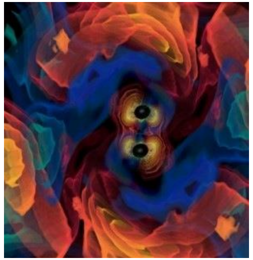

LIGO
LIGO/ Virgo
Fermi/ GBM
IPN Fermi / INTEGRAL
30°
0°
-30°
-30°
16h
12h
8h
Swope +10.9 h
30″
N
E
DLT40 -20.5 d

Computational Challenges

Gravitational Wave Sources/Searches

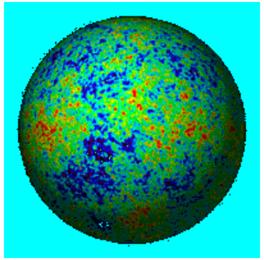


Continuous Waves:
Spinning Neutron Stars



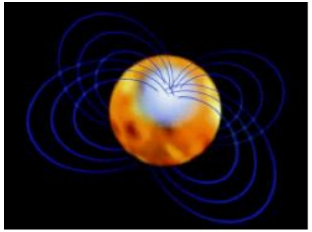
Coalescing Binaries:
Merging black holes and neutron stars

Short Bursts:
Supernovae,
Gamma Ray Bursts



Stochastic Background:
GW from the Big Bang or Astrophysical sources

Gravitational Wave Sources/Searches



Continuous Waves:
Spinning Neutron
Stars

…escing Binaries:
Merging black holes
and neutron stars

Known waveform: matched filter

Short Bursts:
Supernovae,
Gamma Ray B…

…tic Background:
GW from the Big Bang or
Astrophysical sources

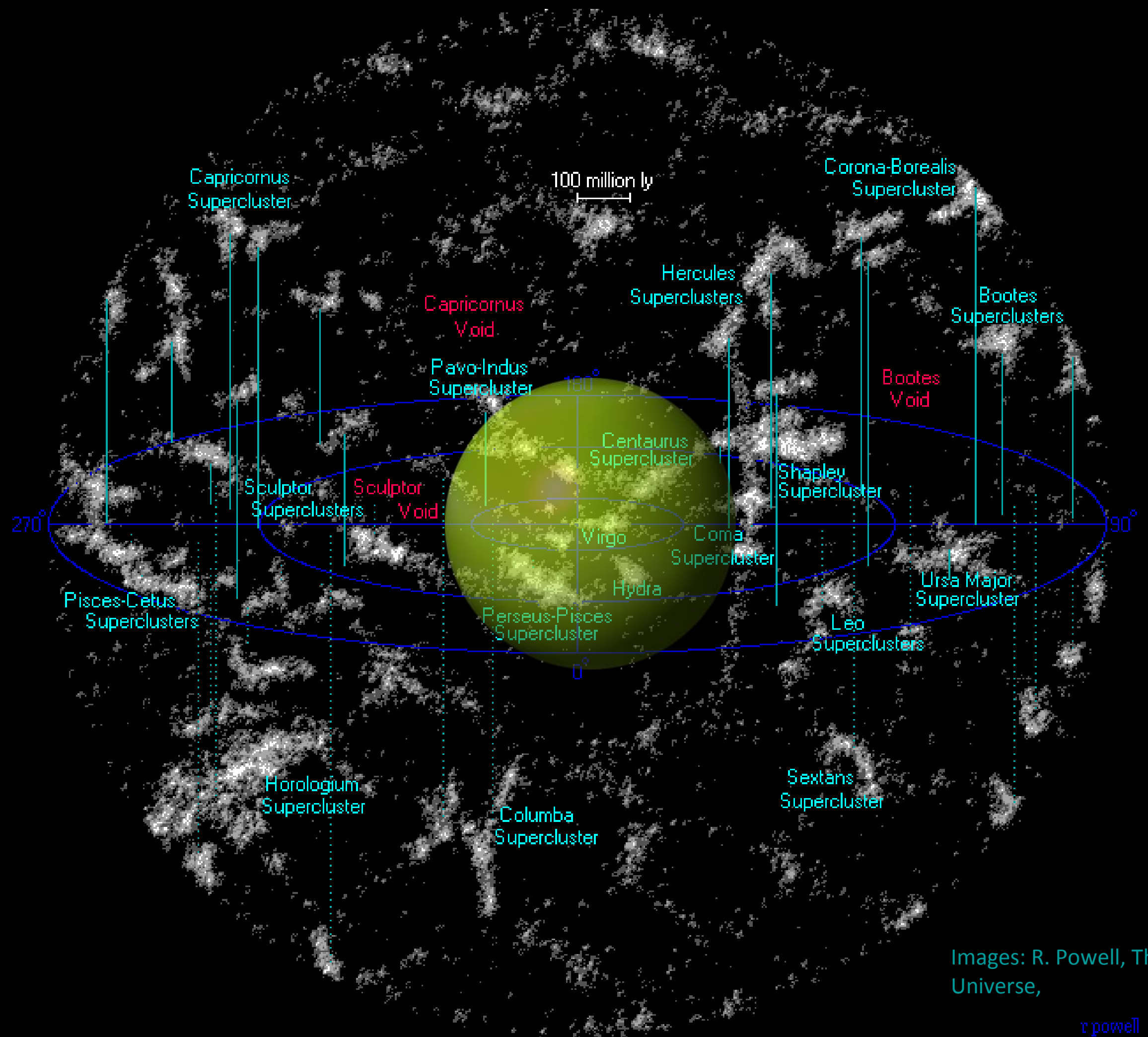
Unknown waveform: cross correlate data

Computational challenges

(Mostly) 'embarrassingly parallel' high throughput computing,
~ 1 Petaflop

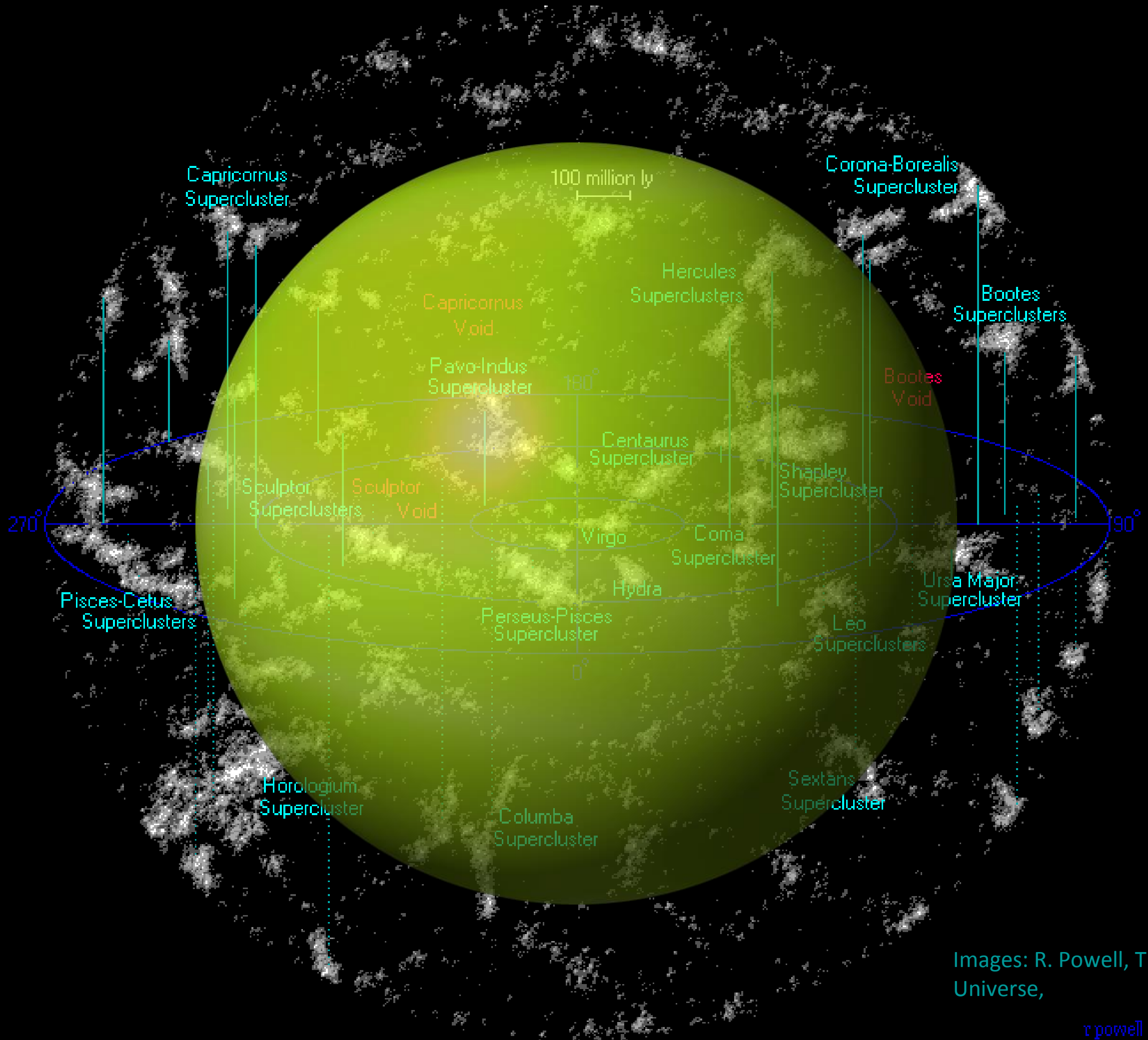
- Einstein@home project for Continuous Waves all sky search;
~ 2.5 Petaflops
- Dominant use on LIGO/Virgo resource:
  - binary search using 300,000 templates. Number and length of templates increases with sensitivity.
  - parameter estimation on events. Scales with number of observed events. Repeat with various waveform models and physical effects incorporated.
  - results in low latency required for electromagnetic followup

2017



Images: R. Powell, The Atlas of The Universe,

2020

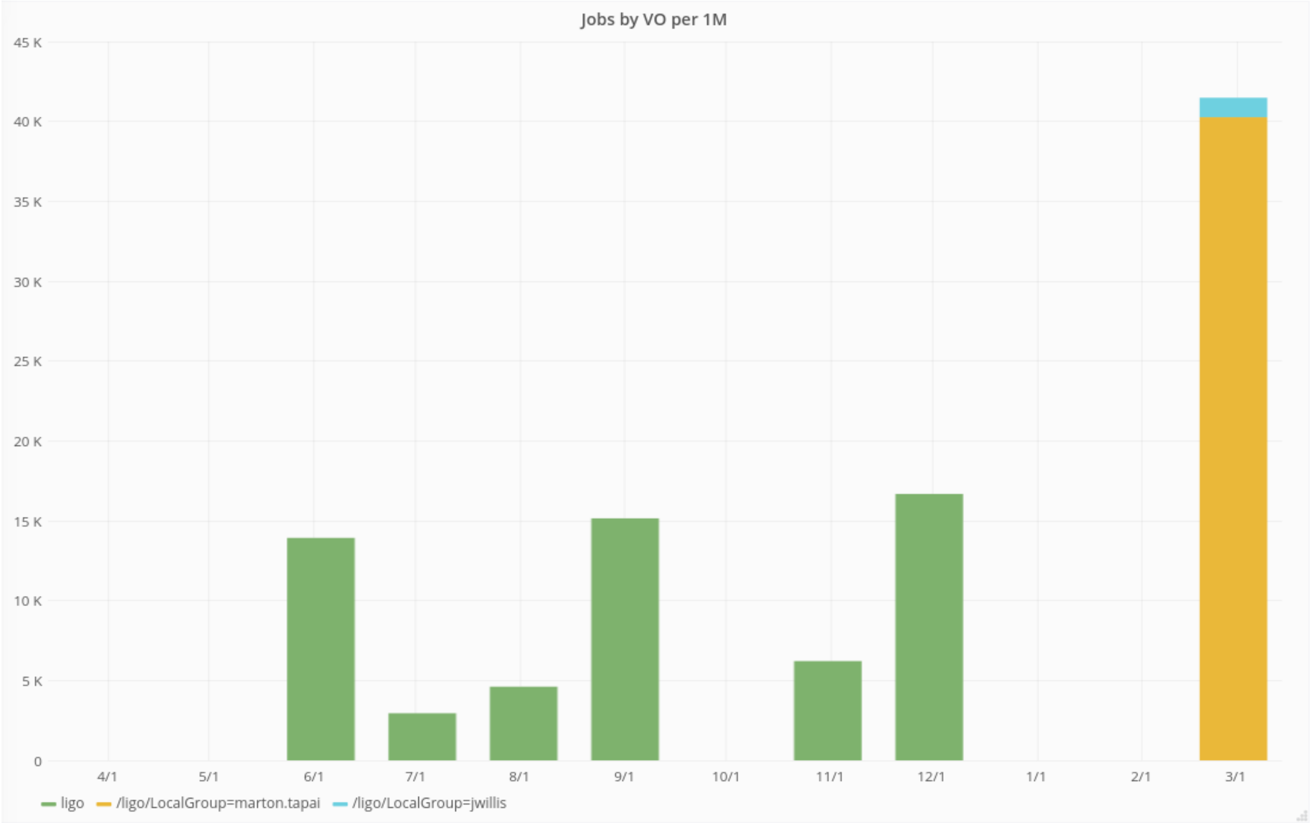


Images: R. Powell, The Atlas of The Universe,

Production computing environments

- Current Baseline: Dedicated/committed LIGO clusters, and Einstein@Home
- Increasing use of other resources:
  - US Open Science Grid
  - European Virgo clusters
  - UK GridPP Tier 0
- Multiple pipelines adapted to take advantage of GPUs
  - Some LSC clusters have a large number of GPUs, e.g. 2400 at Max Planck Institute
- Containerization – light-weight virtualization
- Federated access to resources, including computational clusters, but also e.g. data, web pages, services etc.

LIGO Jobs running at RAL



LIGO Computing Resources

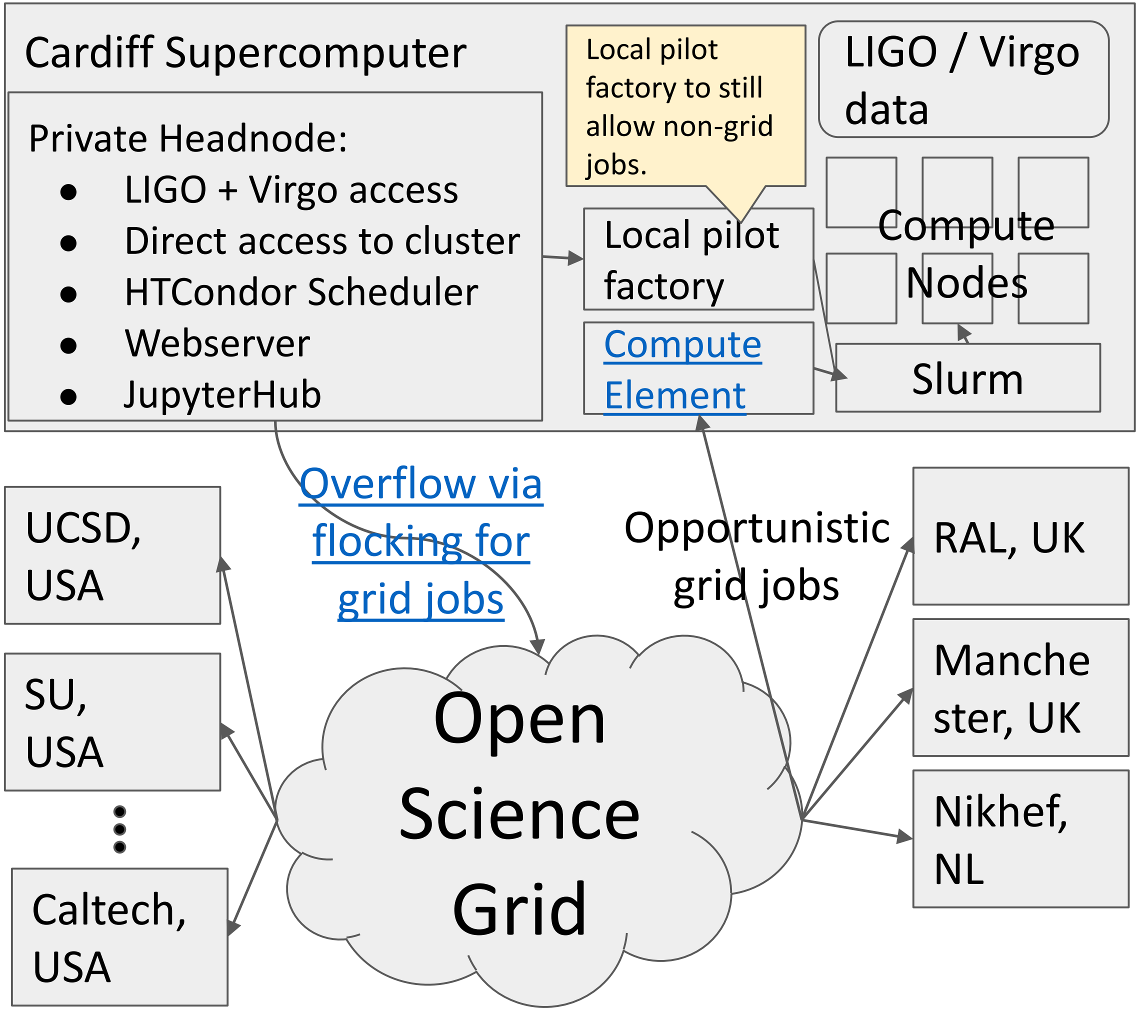
Resources are distributed around the world and inhomogeneous:

- Lab and LSC committed clusters
  - Standard operating system
  - dependencies and software installed on system
  - condor scheduler
- LSC general purpose clusters and Virgo clusters
  - Shared with university or other organization
  - Variety of OS and schedulers
  - Challenges managing software and dependencies
  - Extra hurdles in obtaining accounts and accessing resources

Data rates

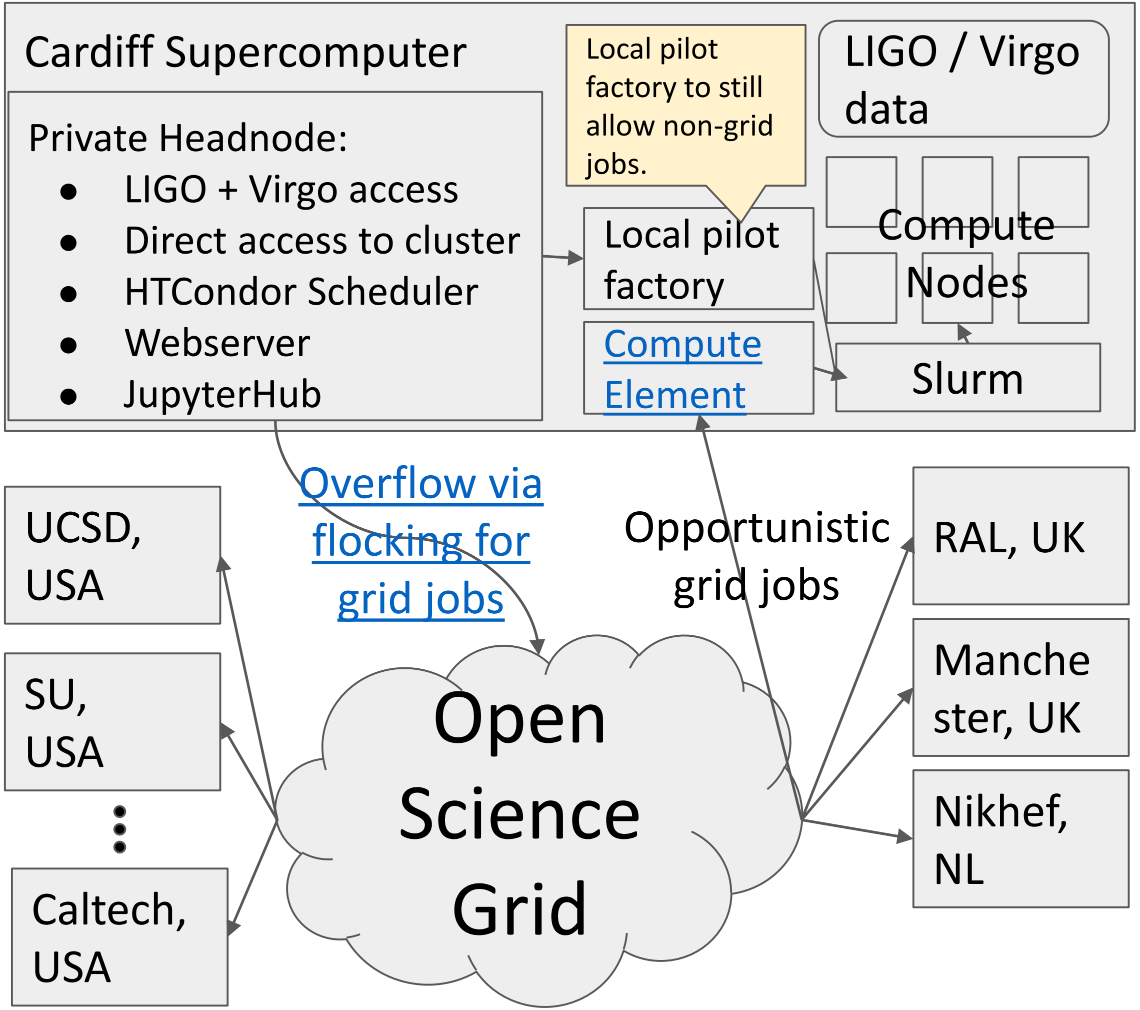
Data Type	File Rate	Data Rate (After Compression)
Raw	492,750 files/yr	10.00 MB/s
Second-Trend	52,560 files/yr	1.10 MB/s
Minute-Trend	8,760 files/yr	0.08 MB/s
RDS	123,188 files/yr	2.00 MB/s
Calibrated Strain	123,188 files/yr	0.12 MB/s
SFTs	17,520 files/yr	0.02 MB/s
Single Interferometer Total:	818000 files/yr	13.32 MB/s
Both LIGO Interferometers:	**1.6M files/yr**	**800 TB/yr**

aLIGO UK upgrade



- Traditional HPC cluster
- Slurm (Currently PBSPro)
- NFS Home, 500GB quota
- Lustre /scratch filesystem
- LIGO/Virgo data on private Gluster storage and most recent 20TB on /scratch
- Dedicated Headnode with HTCondor and local pilots

aLIGO UK upgrade



- Retain local pilot factory
- Use cvmfs for data paths utilising locally stored data
- Add a local compute element to accept jobs from OSG
- Overflow grid jobs to OSG via flocking
- Encourage users to grid enable their workflows
- Aim to remove local pilot factory?