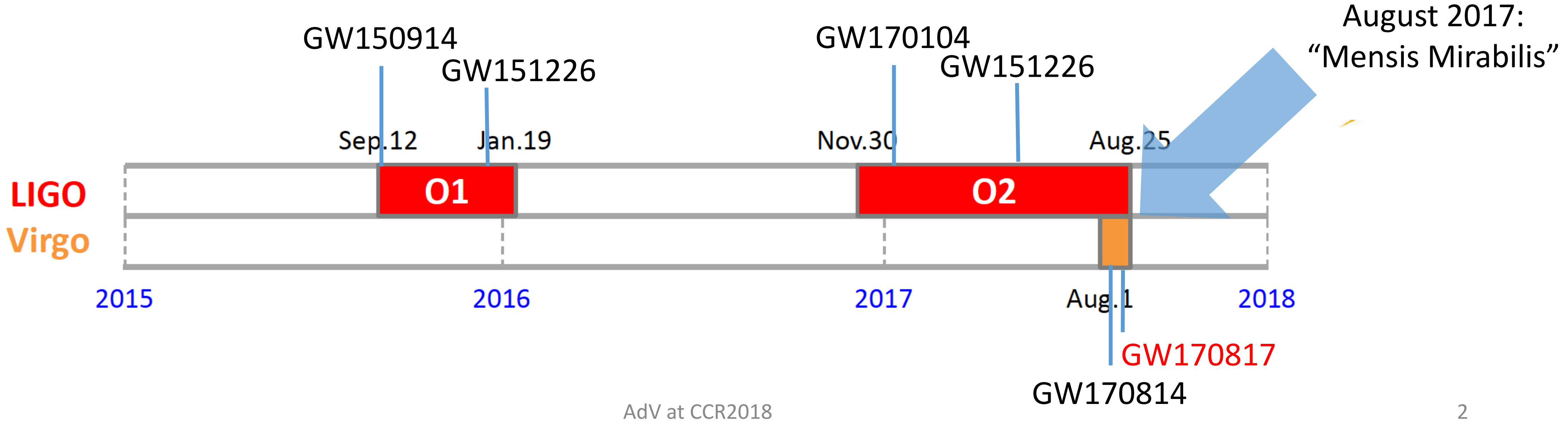
Advanced Virgo Computing

Michele Punturo on behalf of the Virgo collaboration

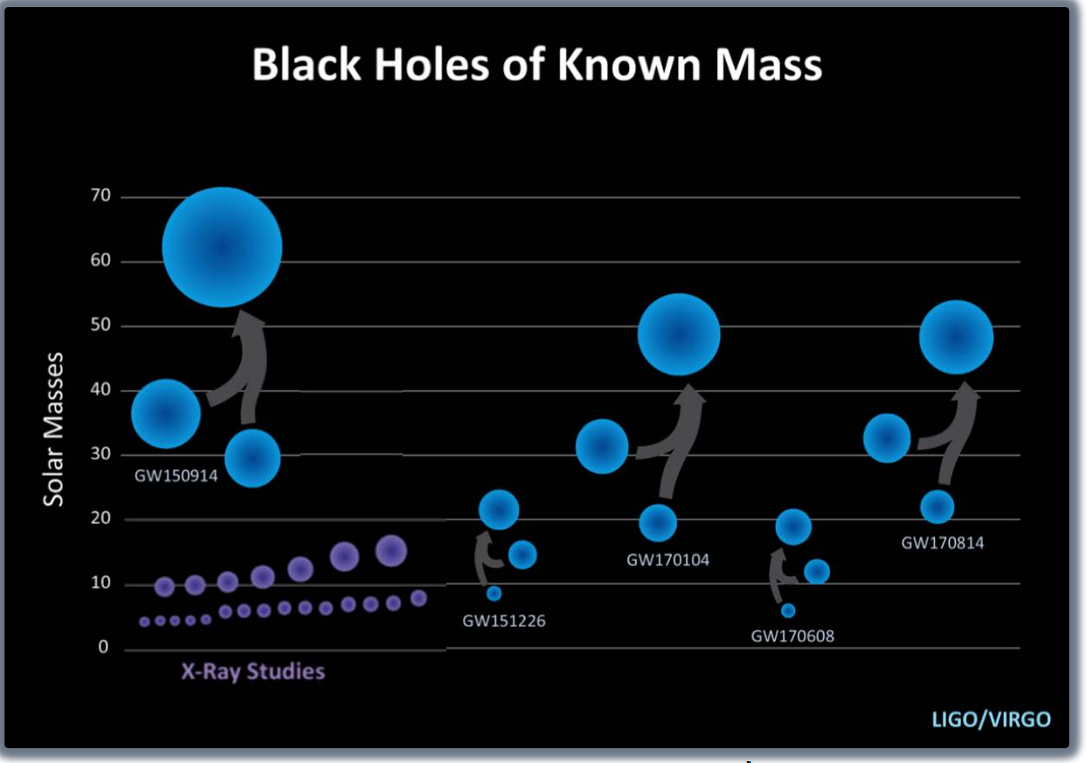
Scientific Run O2

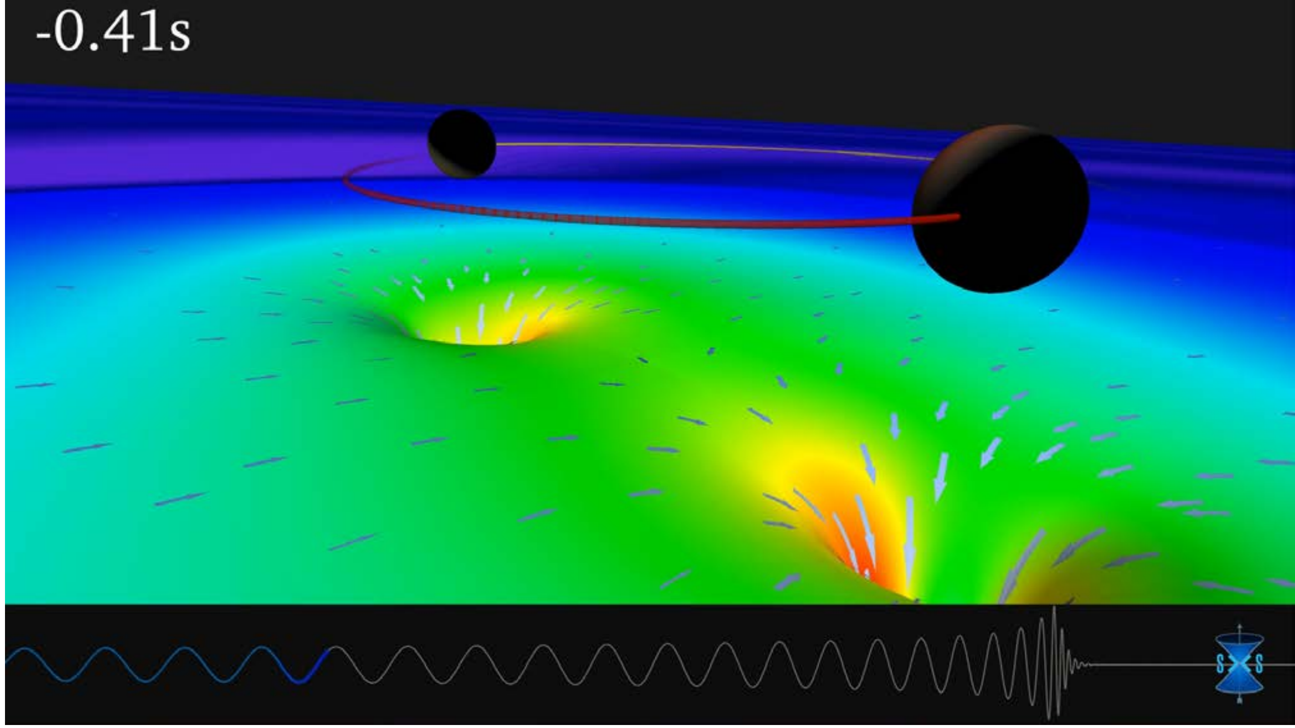
- The LIGO-Virgo collaboration started the scientific run O2 the 30 November 2016 using just the two LIGO detectors
- Virgo detector, after an intense commissioning activity, addressed to achieve a scientifically relevant sensitivity, joined the run the 1st August 2017
- The run concluded the 25th of August 2017
- What happened in the last 3 years?



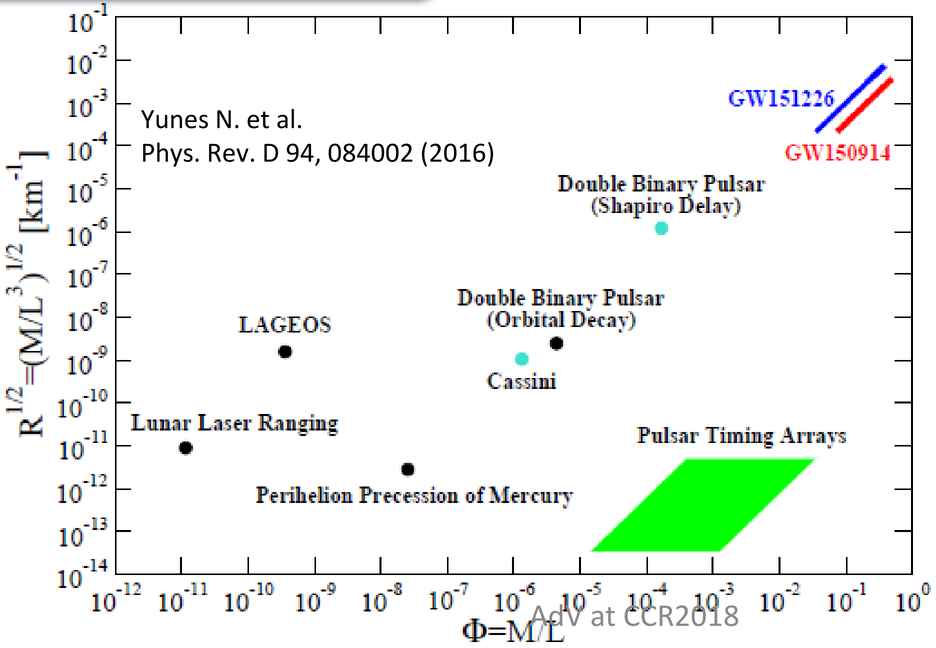
Scientific Revolution

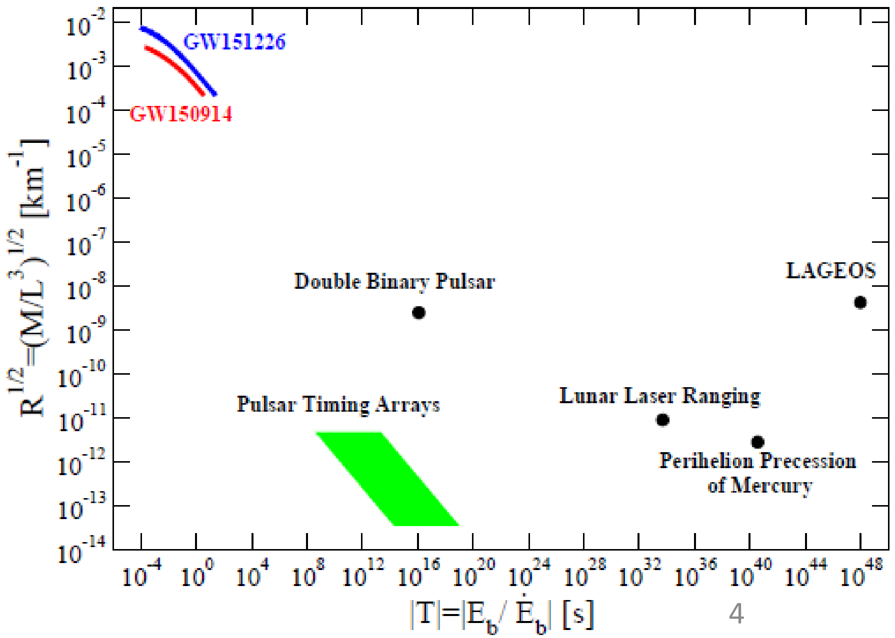
- The detection of GW has been a huge scientific achievement, result of a century of efforts, but actually it is the beginning of a new era in the observation of the Universe
- The discoveries announced by LIGO and Virgo are crucial milestones in Science:
- GW150914: LIGO
  - The first direct detection of GW and the first observation of the a binary black hole system. Confirmation of the Einstein's prediction of GW, birth of the experimental physics of strong field gravity, birth of astrophysics of stellar mass black holes, and confirmation that 'heavy' stellar mass black holes exist.





GW150914 … and its brothers



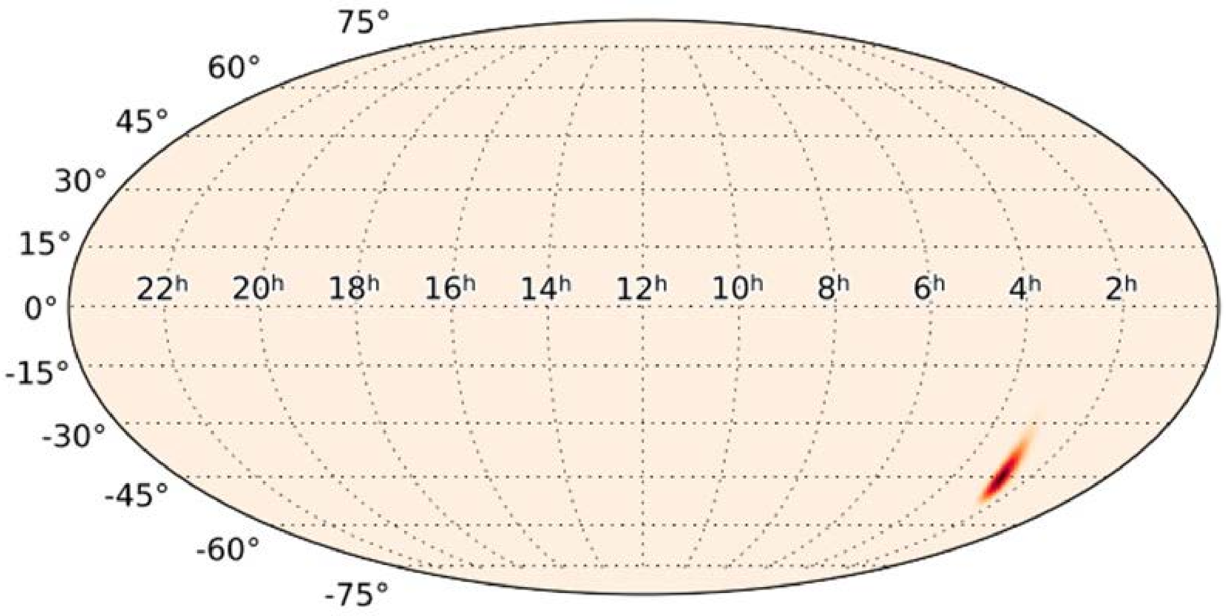


Scientific Revolution

- The detection of GW has been a huge scientific achievement, result of a century of efforts, but actually it is the beginning of a new era in the observation of the Universe
- The discoveries announced by LIGO and Virgo are crucial milestones in Science:
- GW150914: LIGO
  - The first direct detection of GW and the first observation of the a binary black hole system. Confirmation of the Einstein's prediction of GW, birth of the experimental physics of strong field gravity, birth of astrophysics of stellar mass black holes, and confirmation that 'heavy' stellar mass black holes exist.
- GW170814: LIGO Advanced Virgo
  - The first detection in a network of 3 GW detectors of GW emitted by the coalescence of black holes. The birth of the gravitational wave astronomy and astrophysics thanks to the localisation of the GW source

GW170814: Localisation!

- Thanks to Virgo it is possible to localise the GW source→ Astronomy!

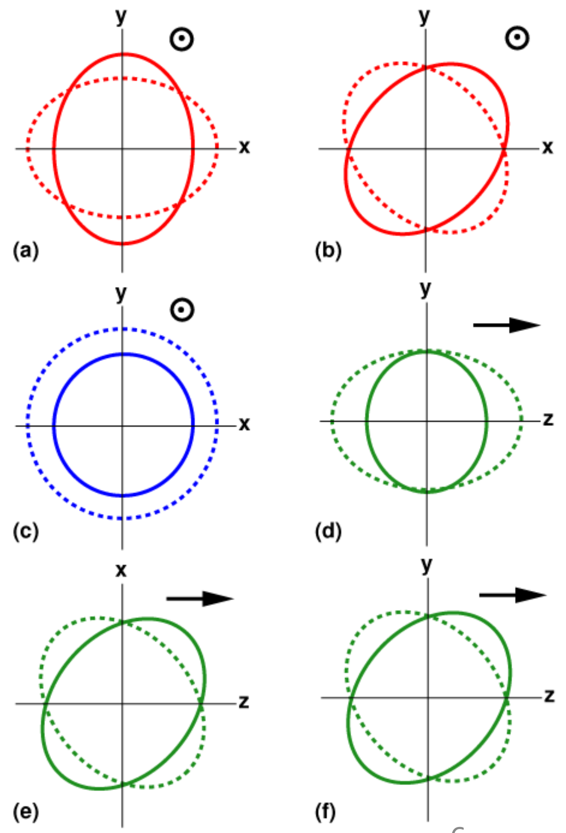


Without Virgo: 1160 deg^2

With Virgo: 100 deg^2

With Virgo (final): 60 deg^2

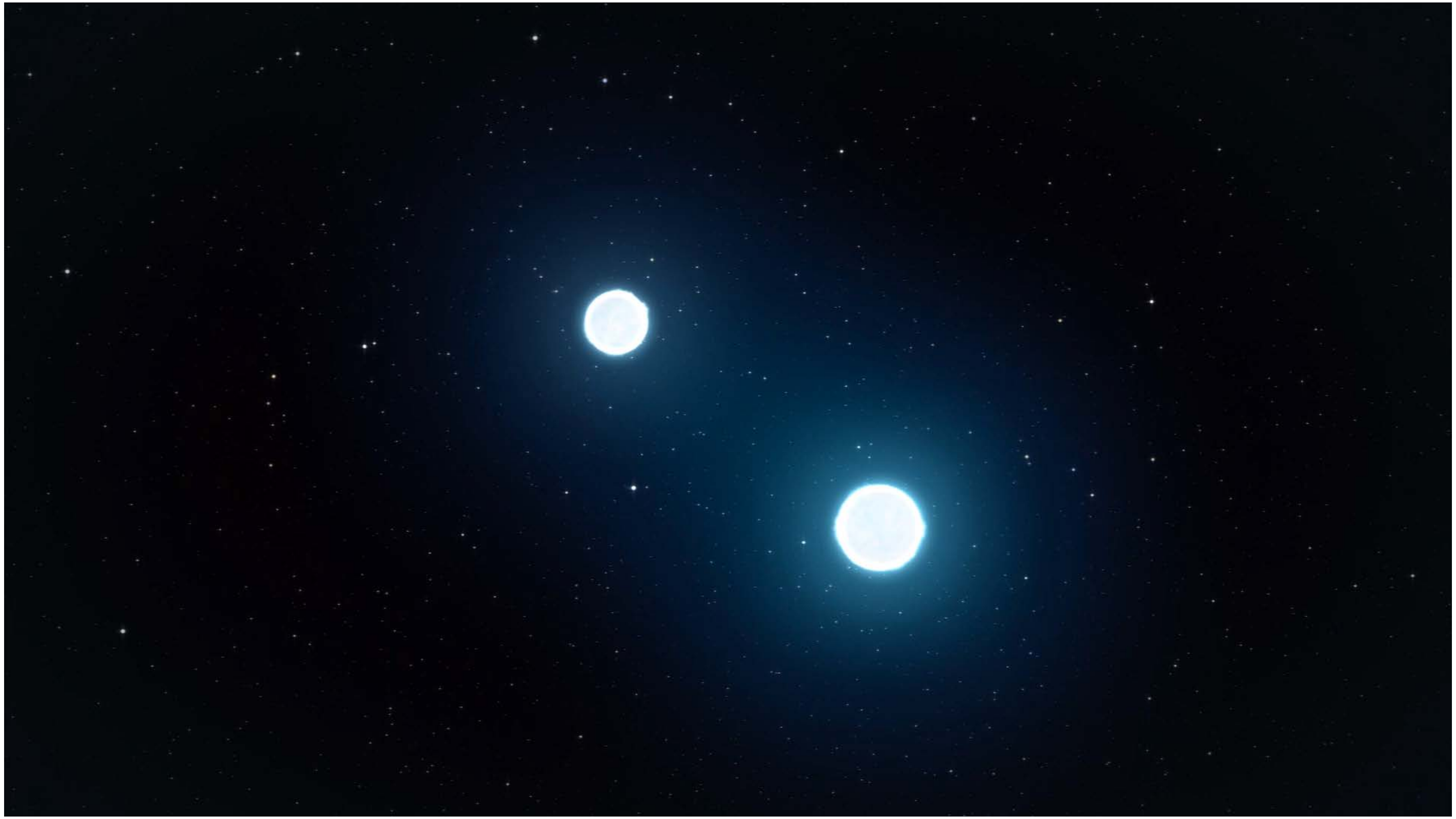
Fundamental Physics!

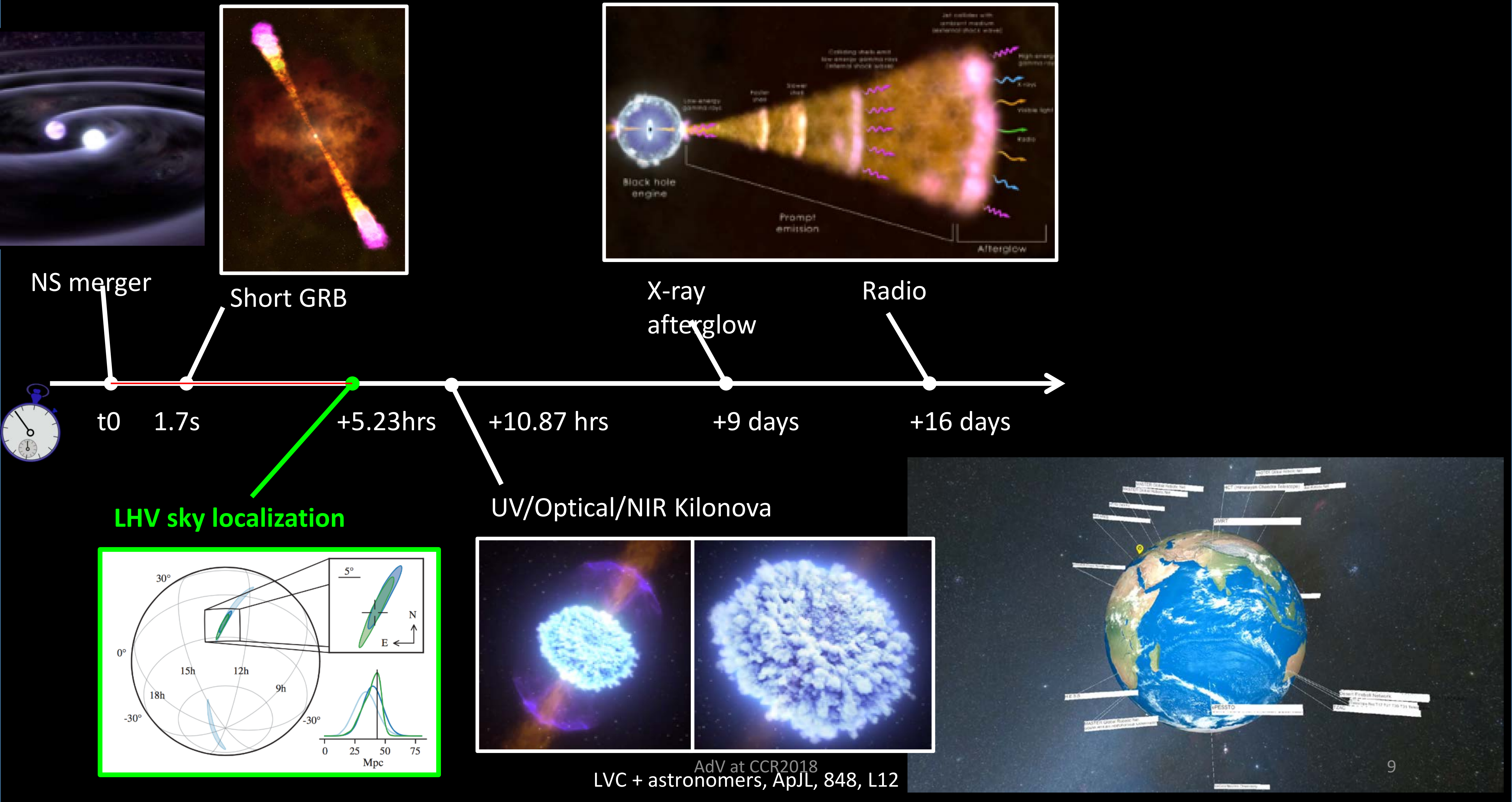


Scientific Revolution

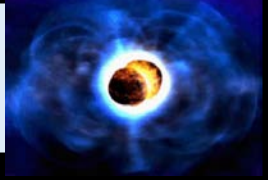
- The detection of GW has been a huge scientific achievement, result of a century of efforts, but actually it is the beginning of a new era in the observation of the Universe
- The discoveries announced by LIGO and Virgo are crucial milestones in Science:
- GW150914: LIGO
  - The first direct detection of GW and the first observation of the a binary black hole system. Confirmation of the Einstein's prediction of GW, birth of the experimental physics of strong field gravity, birth of astrophysics of stellar mass black holes, and confirmation that 'heavy' stellar mass black holes exist.
- GW170814: LIGO Advanced Virgo
  - The first detection in a network of 3 GW detectors of GW emitted by the coalescence of black holes. The birth of the gravitational wave astronomy and astrophysics thanks to the localisation of the GW source
- GW170817: LIGO Advanced Virgo
  - The first detection of the GW emitted by the coalescence of two neutron stars. The beginning of the multi-messenger astronomy, astrophysics and cosmology

The sound (GW) and the images (EM) of a BNS coalescence

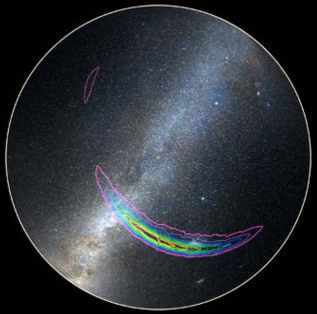



NS merger
Short GRB
X-ray afterglow
Radio
t0
1.7s
+5.23hrs
+10.87 hrs
+9 days
+16 days
LHV sky localization
UV/Optical/NIR Kilonova
Black hole engine
Prompt emission
Afterglow
30°
0°
-30°
15h
12h
9h
18h
5°
N
E
0
25
50
75
Mpc
LVC + astronomers, ApJL, 848, L12

O1 and O2 low-latency GW data analysis pipelines to promptly identify GW candidates and send GW alerts



GW candidates **Sky Localization** **EM facilities**

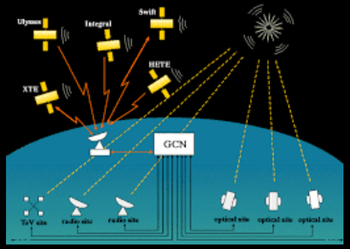


Event validation

Low-latency search
to identify the GW-candidates

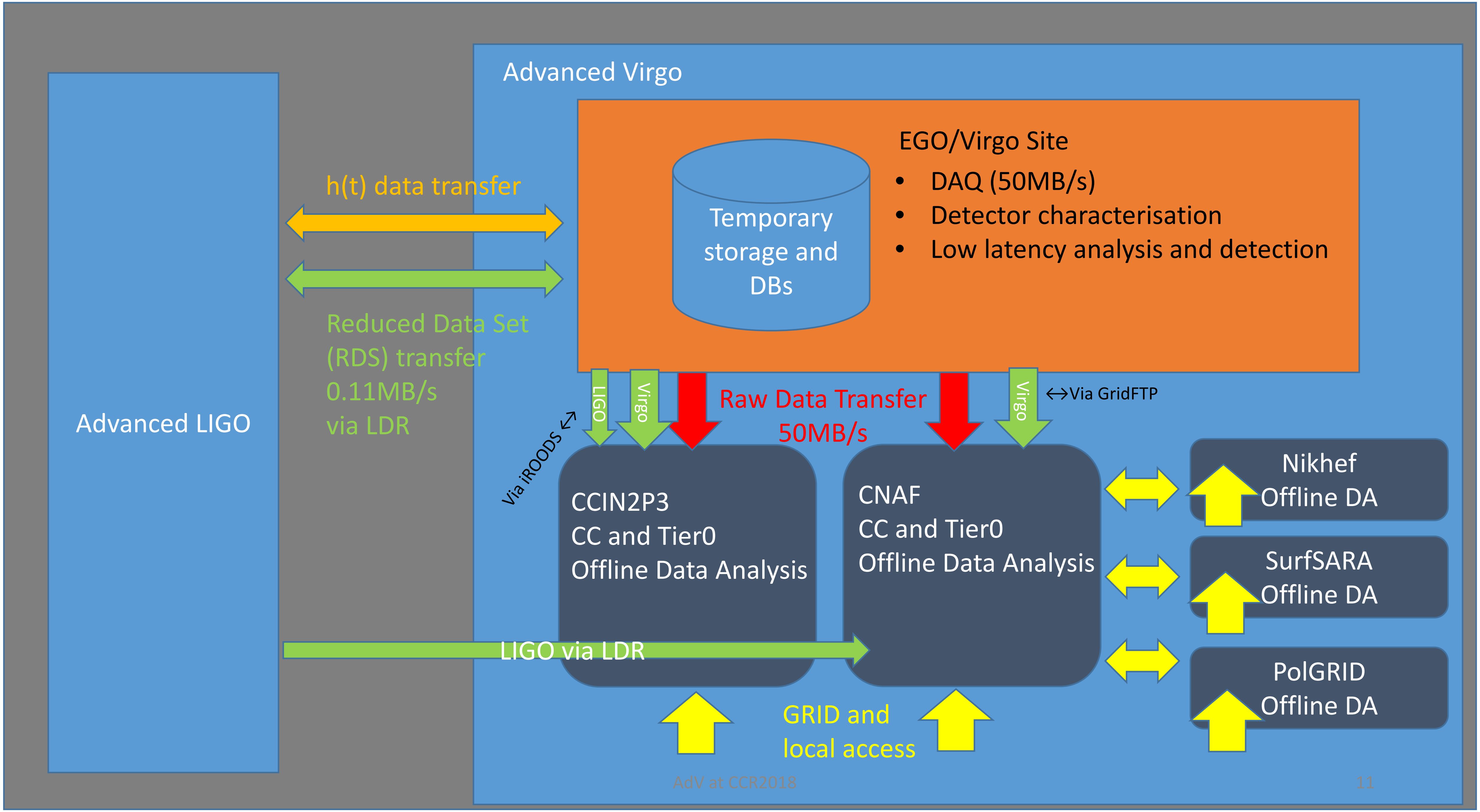
Software to

- select statistically significant triggers wrt background
- check detector sanity and data quality
- determine source localization



a few min → **30 min**

Parameter estimation codes → **Hours,days** → **GW candidate updates**


Advanced Virgo
EGO/Virgo Site
• DAQ (50MB/s)
• Detector characterisation
• Low latency analysis and detection
Temporary storage and DBs
h(t) data transfer
Reduced Data Set (RDS) transfer 0.11MB/s via LDR
Advanced LIGO
LIGO
Virgo
Virgo
Raw Data Transfer 50MB/s
↔Via GridFTP
Via iROODS ↔
CCIN2P3
CC and Tier0
Offline Data Analysis
CNAF
CC and Tier0
Offline Data Analysis
Nikhef
Offline DA
SurfSARA
Offline DA
PolGRID
Offline DA
LIGO via LDR
GRID and local access
AdV at CCR2018
11

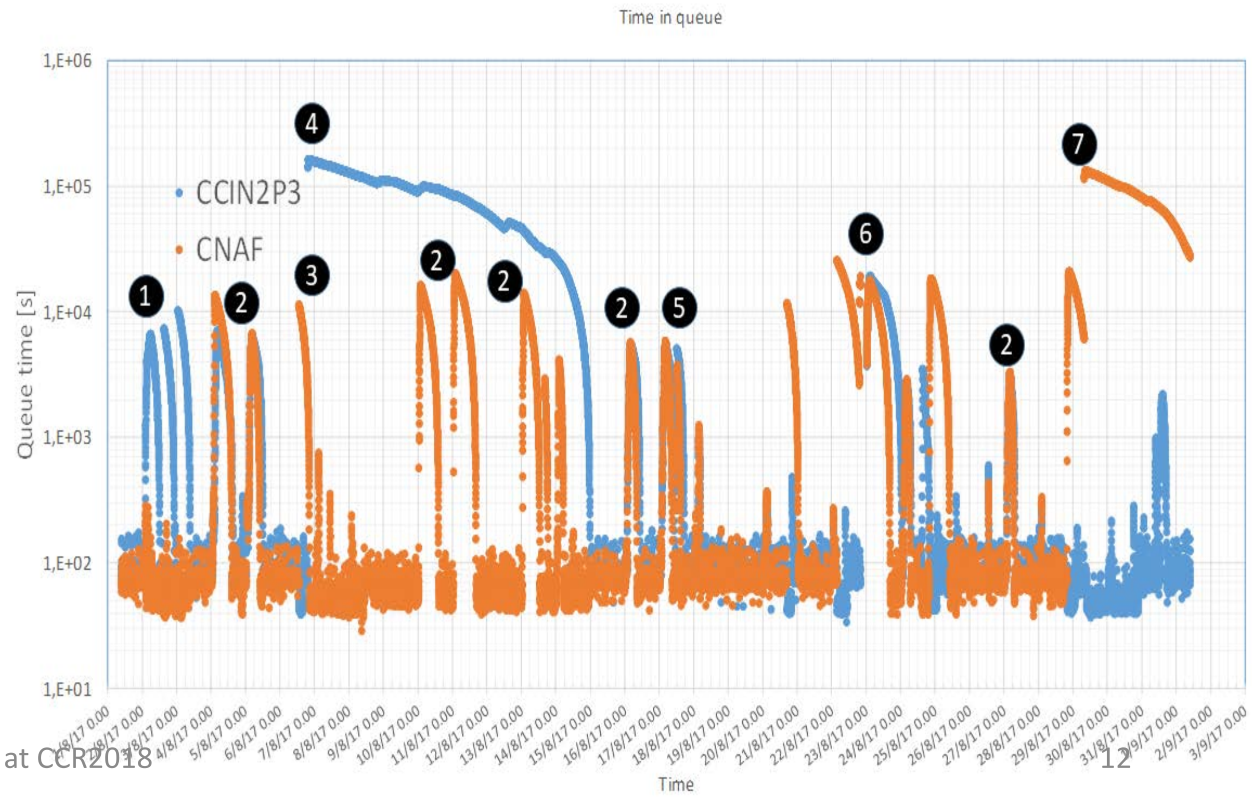
Data transfer

- O2 constrains:
  - 1Gb/s WAN bandwidth at EGO
  - Too small local storage
  - Access to CNAF Storage: GridFTP
  - Access to CCIN2P3: iRODs

Need to transfer data "on time"

Ad hoc "double" transfer procedure

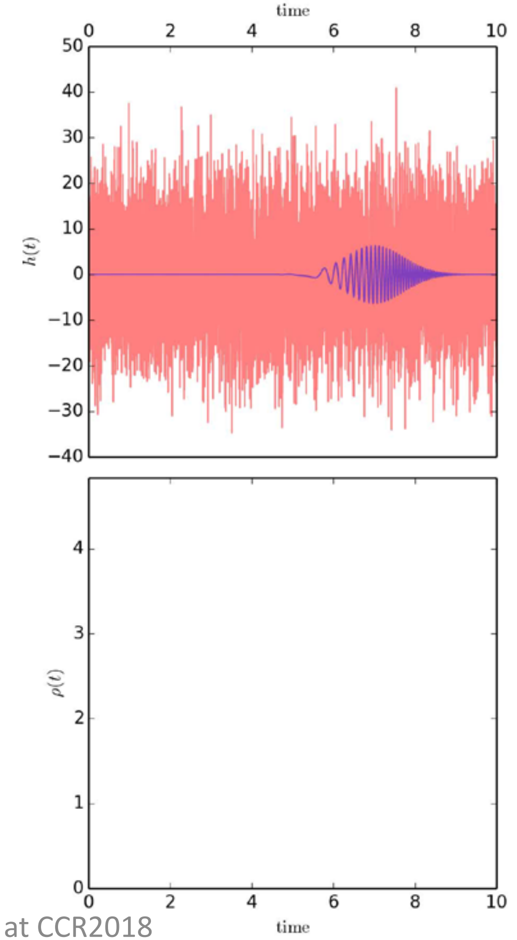
- Result:
  - Fragilities and many troubles
- Current activities:
  - Find a CNAF+CCIN2P3 common protocol
    - Webdav?
  - Think to a future standard procedure:
    - Virgo: DIRAC?
    - LIGO: Rucio to replace LDR?

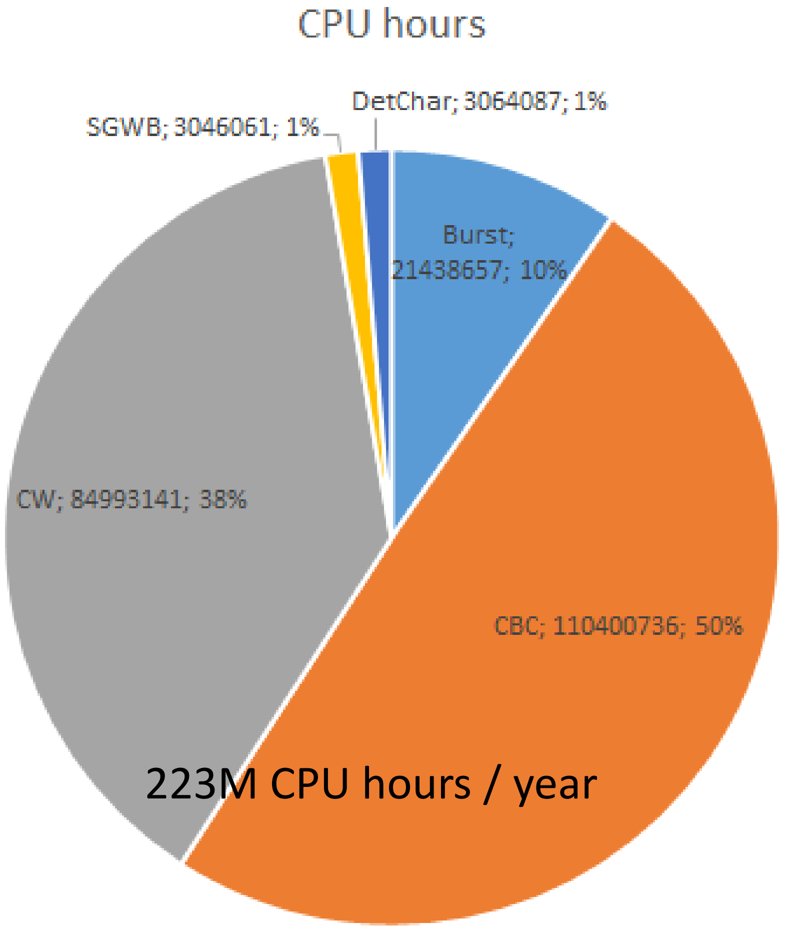


(mainly) Offline Analysis

- LIGO and Virgo are looking for several GW sources → several analysis
- Each analysis can be investigated with different methods → several pipelines

- Transients:
  - Modelled search:
    - Coalescing Compact Binary Systems (Neutron Star-NS, Black Hole-NS, BH-BH): Strong emitters, well modelled
  - Unmodelled (bursts)
    - Asymmetric Core Collapse Supernovae weak emitters, not well-modeled (‘bursts’), transient
    - Cosmic strings, soft gamma repeaters, pulsar glitches
- Continuous signals
  - Stochastic search
    - Cosmological stochastic background (residue of the Big Bang, cosmic GW background, long duration)
    - Astrophysical stochastic background
  - Continuous search
    - Spinning neutron stars (known waveform, long/continuous duration)





Network of GW detectors

LIGO Scientific Collaboration:
- 1263 collaborators (including GEO)
- 20 countries
- 9 computing centres
- ~1.5 G$ of total investment

Virgo Collaboration:
- 343 collaborators
- 6 countries
- 5 computing centres
- ~0.42 G€ of total investment

KAGRA Collaboration:
- 260 collaborators
- 12 countries
- 5 computing centres
- ~16.4 G¥ of construction costs

Network of Computing Centres

LIGO Scientific Collaboration:

- 1263 collaborators (including GEO)
- 20 countries
- 9 computing centres
- ~1.5 G$ of total investment

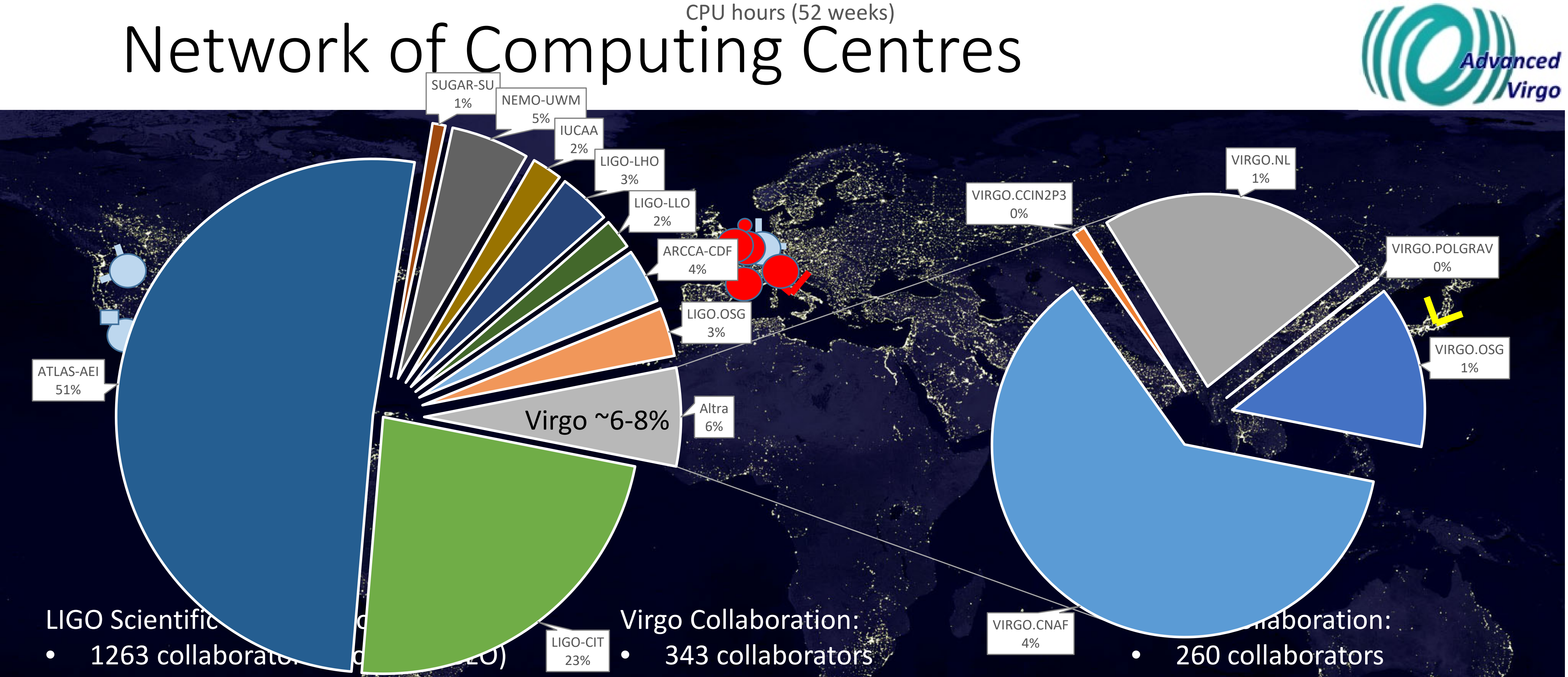
Virgo Collaboration:

- 343 collaborators
- 6 countries
- 5 computing centres
- ~0.42 G€ of total investment

KAGRA Collaboration:

- 260 collaborators
- 12 countries
- 5 computing centres
- ~16.4 G¥ of construction costs

Network of Computing Centres



LIGO Scientific

- 1263 collaborato ... O)
- 20 countries
- 9 computing centres
- ~1.5 G$ of total investment

Virgo Collaboration:

- 343 collaborators
- 6 countries
- 5 computing centres
- ~0.42 G€ of total investment

laboration:

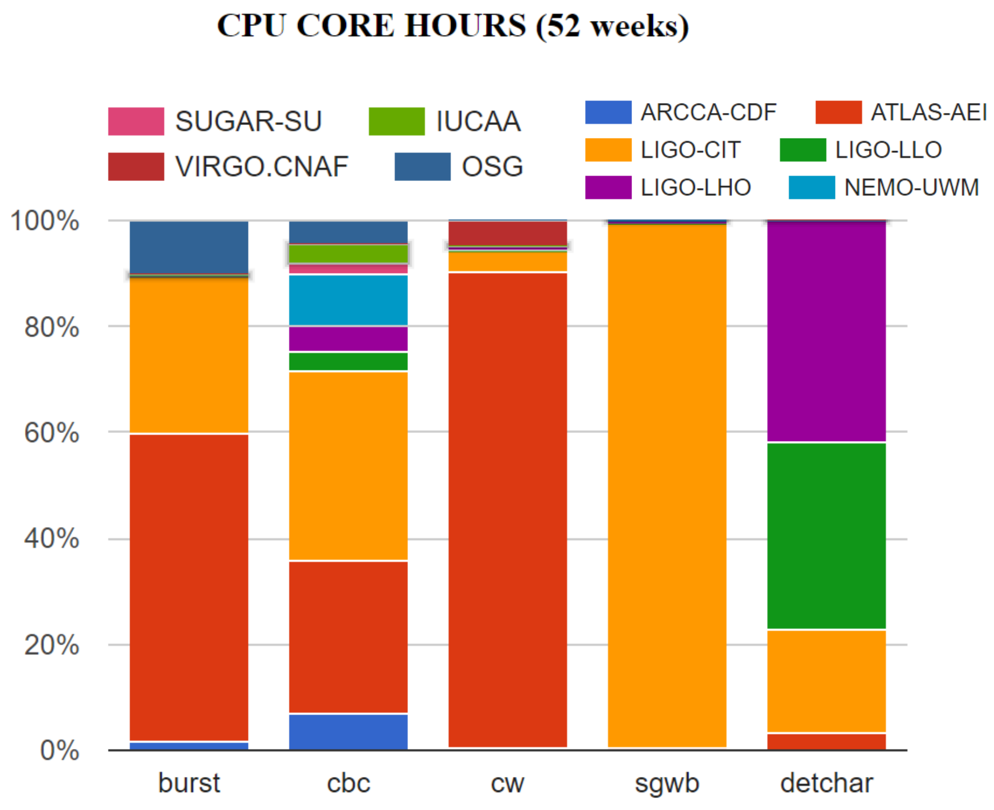
- 260 collaborators
- 12 countries
- 5 computing centres
- ~16.4 G¥ of construction costs

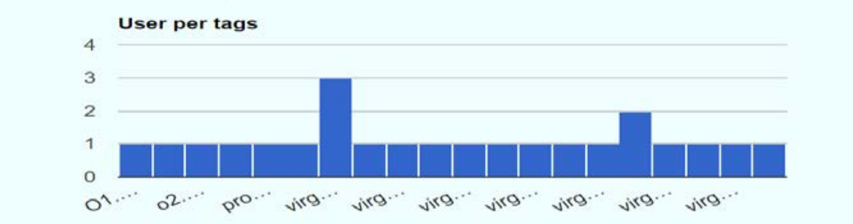
Why so small Virgo contribution?

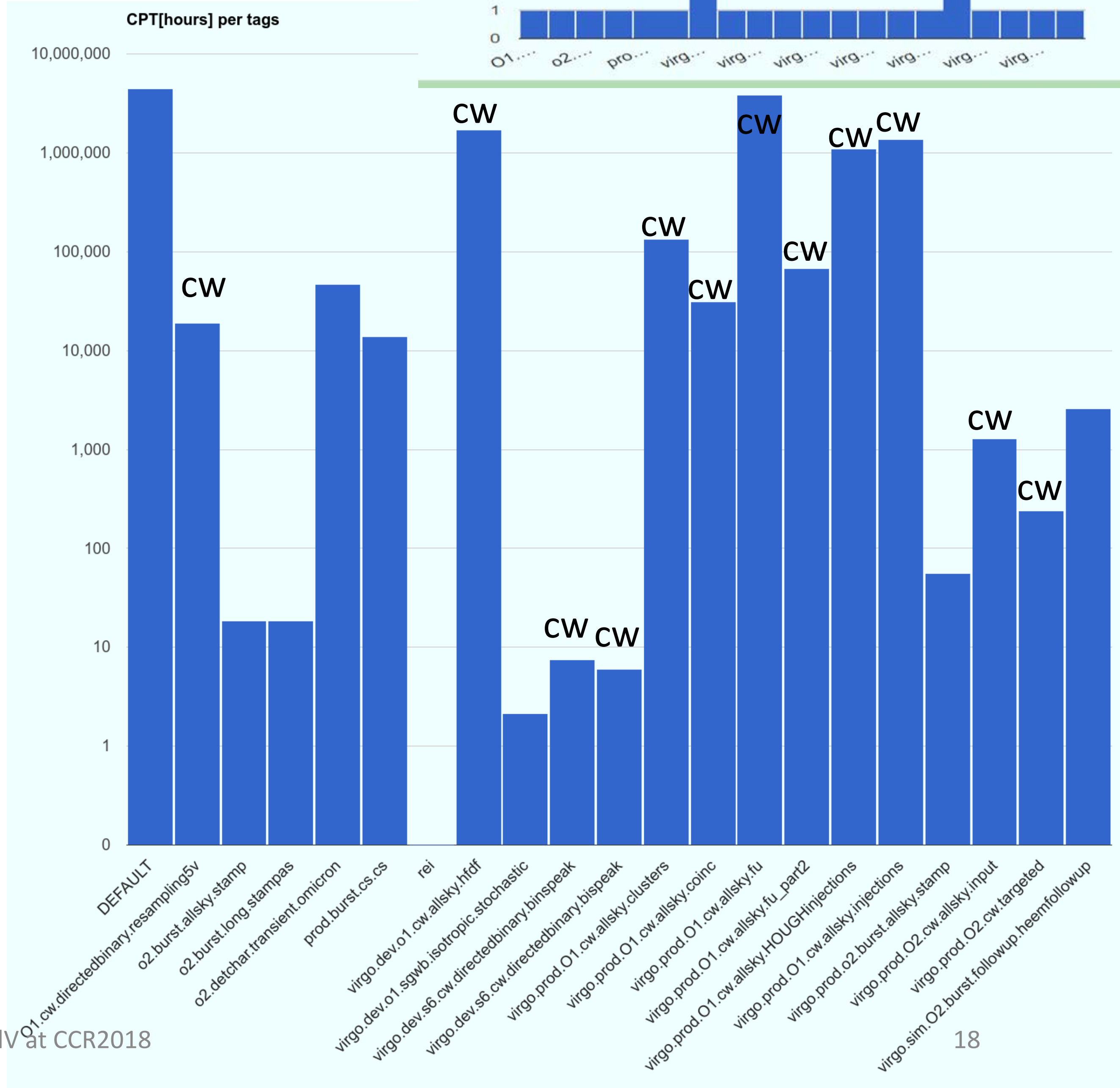
- Not enough resources:
  - (Very) roughly ≤20% of the total LVC resources (in power)
- But the major problem is the computing model:
  - For the majority of the LVC common pipelines
    - Condor clusters fully devoted to LIGO
    - Pipelines looking for data and libraries in a local shared file system
    - (many) Pipelines intrinsically uncompliant with GRID
  - Difficult to have them running at CNAF, CCIN2P3, Nikhef, ….

Computing load distribution

- The use of the CNAF is almost mono-analysis
- Diversification is give by OSG access







Evolutions

- We are signing a new agreement with LIGO that is forcing us to provide about 20-25% of the whole computing energy
- Need to solve this issue
  - 1st step: to harmonise the access to the Virgo resources
  - Thanks to the CNAF and EGI support we are testing DIRAC for
    - Workload management
    - Data management
    - Data transfer
      - We are at level of "hypothesis"
      - We would like the evaluate the possibility to use DIRAC to transfer our data from EGO/Virgo to CNAF and CCIN2P3
      - Still to verify if it matches our requirements

DIRAC: workload management

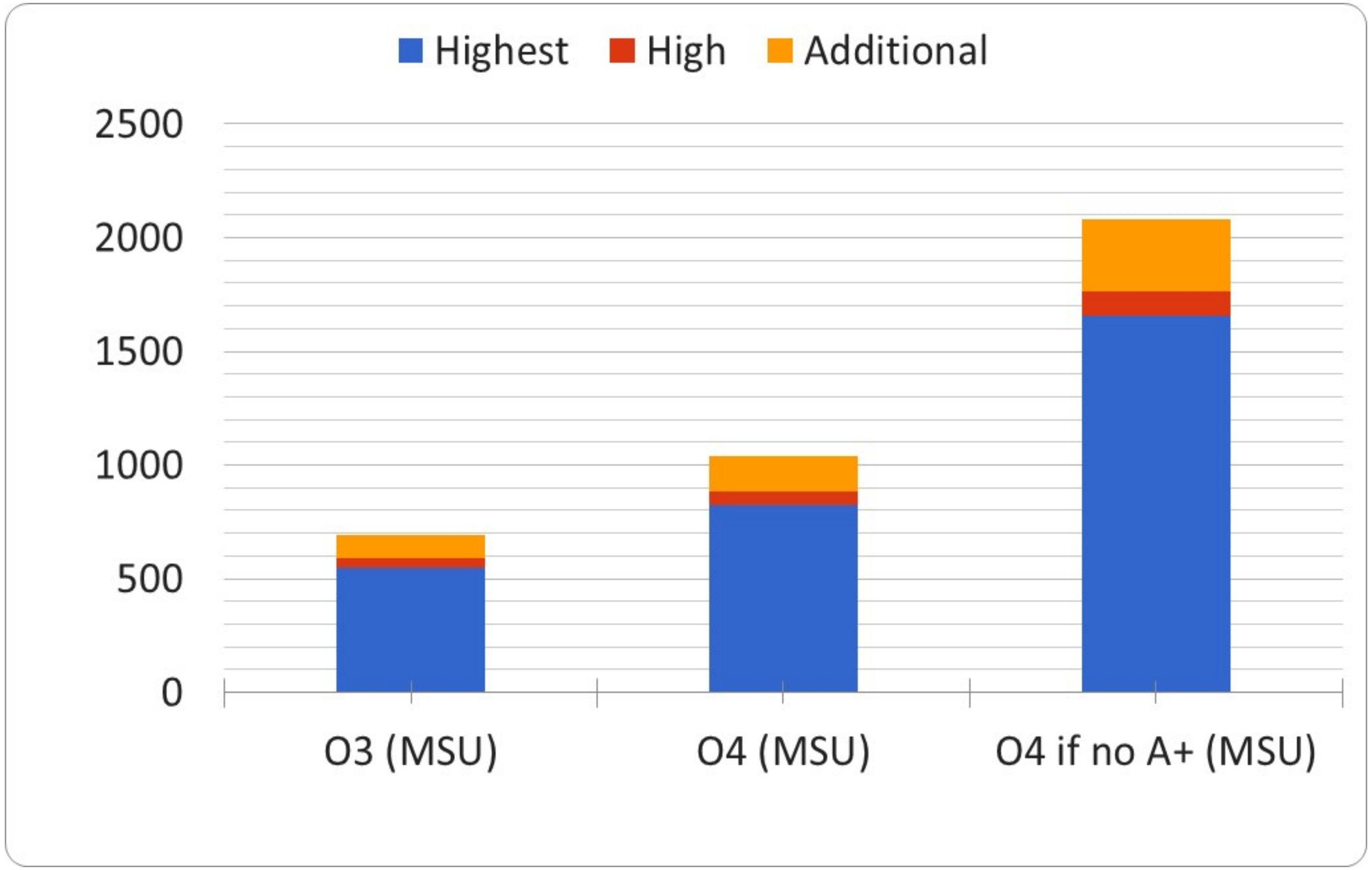
- Virgo has been added to the Dirac framework
  - Dirac client installation is straightforward
- A test campaign has been done in order to understand if it can be a replacement for standard grid job submission (WMS dismissed, LFC dismissed, lcg-* tools non more available under Centos7, increasing number of accessible sites,…)
- Storages at CNAF, Nikhef, SARA and Cyfronet have been published in Dirac (some configuration work needed by CC admins)
- We are now able to submit jobs to any of the following site: CNAF, Nikhef, SARA, Lyon, Cyfronet
- Input/output data management via the Dirac file catalogue works well
- Open Issues:
  - Current Dirac version cannot use GFAL functions for data movement
  - Need to perform a production-like test to check robustness of the framework and of the file catalogue
  - Opportunistic use of other CCs (VO configuration issue)
  - Try to include LIGO resources under Dirac (for testing purposes)?

DIRAC: Data Management

- DB at CNAF
- We tested performances by adding new entries, metadata and queries
  - No problems
- Still to manage the files located at CCIN2P3
- To create the interface with our analysis software that uses a common GW standard (FFL – Frame File Library)

Future: Increase of CPU power needs

- O3 run will start in February 2019 and will last for 1 year
- 3 detectors:
  - Non linear increment for the coherent pipelines
    - HL, HV, LV, HLV
- 4 detectors:
  - At the end of O3, probably KAGRA will join the science run
- Some of the pipelines will be based on GPUs



Conclusions

- Virgo and LIGO opened a new era in the observation of the Universe:
  - Multimessenger astronomy
    - Huge new discoveries potential
  - Computing models are new and surely under-optimised
    - Difficulties on matching current architecture with available infrastructures
  - Computing resources needs in rapid grown
  - What we need?
    - Expertise
    - Human and HW Resources
    - Infrastructures
    - New models (virtualisation and cloud?)