**Burst sources:**

- **Compact Binary Coalescence**
  - Coalescing Compact Binary Systems (Neutron Star-NS, Black Hole-NS, BH-BH): Strong emitters, well modelled

- **Unmodeled transient bursts**
  - Asymmetric Core Collapse Supernovae: weak emitters, not well-modelled (‘bursts’), transient
  - Cosmic strings, soft gamma repeaters, pulsar glitches

**Continuous sources:**

- **Continuous stochastic background**
  - Cosmological stochastic background (residue of the Big Bang, cosmic GW background, long duration)
  - Astrophysical stochastic background

- **Continuous waves**
  - Spinning neutron stars (known waveform, long/continuous duration)
"Multimessenger Observations of a Binary Neutron Star Merger"

B. P. Abbott et al. 2017 ApJL 848 L12

Low-latency searches

Detector sanity, Data Quality, localization,…

Event validation

Sky localization

Public Alert

Low-latency searches

GW candidate

A few minutes

½ hour

On-site

Parameter estimation

GW Candidate Update

Hours, days
AdV+ to be carried out in parallel with LIGO’s A+ upgrade

Five year plan for observational runs, commissioning and upgrades

<table>
<thead>
<tr>
<th>Year</th>
<th>2019</th>
<th>2020</th>
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<tbody>
<tr>
<td>Virgo AdV+ Proposed upgrade plan</td>
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<td>Observing Run O3 (&gt; 60 Mpc)</td>
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<td>Design, infrastructure preparation for AdV+</td>
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<td>Install signal recycling (AdV) and frequency dependent squeezing (AdV+)</td>
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<td>Observing Run O4 (&gt; 120 Mpc)</td>
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<td>Install AdV+ large mirror upgrades</td>
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<td>AdV+ commissioning</td>
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<td>Observing Runs</td>
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<td>LIGO A+ Upgrade plan (see LIGO-G1702134)</td>
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<td>A+ integration into chambers</td>
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<td>A+ commissioning</td>
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<tr>
<td>Completion AdV+ and A+</td>
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Note: duration of O4 has not been decided at this moment
AdV+ is part of a strategy to go from 2nd generation to Einstein Telescope
Raw Data, $\sim1$PB/yr:

- **Full Bandwidth Raw**, not exported (7.5-10 TB/day)
- **Raw Data**: downsampling, calibrated and uncalibrated h(t) (3-4 TB/day)
- **A few levels of reduced data sets** for various uses

Data for physics, $\sim5$TB/yr/detector:

- **Virgo h(t)**: calibrated «strain» data
  - Sampled at 10 KHz, as $\sim$1kSec frame files
  - Includes state vector (data quality flags, vetoes,...)

- **LIGO h(t)**
  - Copied online to EGO for low-latency searches and exported to CCs for offline analysis

- **KAGRA h(t)**
  - Coming soon...

\[ h(t) = \frac{12G}{R c^4} \ddot{I}(t) \]
Stefano Bagnasco - INFN Torino
VIRGO and Gravitational Waves computing in Europe - 9/3475
Many activities still based on legacy architectures, heterogeneous environment, custom tools that increase the management and maintenance burden on a small community.

Analysis pipelines are very heterogeneous (Matlab, Phyton, C++,...) and often tightly coupled to a specific running environment (Grid submission, HTCondor cluster, shared disk,...).

As a consequence of this, there is no clear boundary between «middleware» and analysis code proper and little or no common framework.

Single-interferometer data have no or very little scientific use.
Need to define and deploy a common and sustainable GW computing environment

- Provide a uniform runtime environment for offline pipelines
- Full interoperability between Virgo, LIGO (and KAGRA)
- Provide scalability and the opportunity to exploit heterogeneous resources
- Adopt mainstream, widely used tools, leveraging upon HEP experience

Enter **IGWN** – the International Gravitational Waves observatories Network

- A coordination effort aimed at jointly discussing the computing policy, management, and architecture issues of LIGO, Virgo, and KAGRA.
- **Caveat:** this (partial) summary sees things from the Virgo point of view!
**Bulk data transfer**
Safely transfer all data to custodial storage in CCs

**Software packaging and distribution**
Make pipeline software available ubiquitously

**Data distribution**
Make h(t) data available to worker nodes anywhere

**Data cataloguing and bookkeeping**
Organize all data and metadata and provide querying capabilities

**Workload management**
Provide a uniform job submission and runtime environment

**High-level workload orchestration**
Keep a database of all jobs and allow the enforcement of priorities

**Monitoring and accounting**
Monitor distributed computing and provide reliable accounting
Currently no «data catalogue» like the ones most HEP experiments use

- Metadata encoded in PFNs
- Data discovery through custom tool scanning filesystems

CVMFS used to export a filesystem-like namespace and provide uniform access to \( h(t) \) data

- Authenticated access through OSG-developed x.509 plugin
- «External data» feature + client plugin used to read actual bytes from...

StashCache as Content Delivery Network

- xCache-based cache hierarchy, http protocol
- see e.g. I. Sfiligoi’s presentation on Tuesday
- Currently two instances in the EU: UvA (production), CNAF (under test)
• **Step 1:** use Rucio to manage bulk raw data transfer to custodial storage
  - See also M. Lassnig’s presentation on Monday
  - HA deployment studies
  - Multiple checksum algorithms fix

• **Step 2:** use it as a full-fledged Data Catalogue (under discussion)
  - Possibly with a federated architecture
  - Another possible development: POSIX mount to replace CVMFS (kicked off at last Rucio Code Camp at CERN)
OVERALL PICTURE: DATA

Local activities @ EGO omitted and only one CC for clarity

Bulk data transfer

Low-latency data transfer

kafka

CNAF

Another Fancy Site

A Fancy Site

CVMFS + Caching

Or hierarchy thereof

xCache

VIRGO and Gravitational Waves computing in Europe - 15/3475

Stefano Bagnasco - INFN Torino
Use HTCondor as a uniform job submission layer

- To local HTCondor clusters if needed
  - Some pipelines already rely on HTCondor DAGs for dependencies
- To common Condor Pools
  - Exploit Grid resources through GlideIn pilots
- To on-demand HTCondor Virtual Clusters
  - Through DoDAS Distributed on-Demand Analysis Services
  - Exploit heterogeneous or opportunistic resources
  - Cater to special needs like off-site low-latency searches
Local activities @ EGO omitted and only one CC for clarity

* Here magic happens: see S. Dal Pra’s presentation on Monday
WHERE ARE WE?

Bulk data transfer
Rucio

Software packaging and distribution
CVMFS (+ Conda + Singularity)

Data distribution
CVMFS (but see above) + StashCache

Workload management
HTCondor and, possibly, DoDAS

Data cataloguing and bookkeeping
Probably Rucio again

High-level workload orchestration
Possibly DIRAC, custom tools if it’s an overkill

Monitoring and accounting
TBD, maybe DIRAC again?

Mostly decided except implementation details, under deployment or active development

Up next?

Not an immediate priority
CONCLUSIONS

- GW computing (in EU and elsewhere) is making a significant step forward towards organized computing
- IGWN means a coordinated and common infrastructure between the collaborations
- The adoption of common mainstream solutions like HTCondor or Rucio also means GW joins the larger physics computing community
- …which bodes well for the proposed 3G interferometers computing effort in a decade from now.