The status of Virgo

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On behalf of the Virgo Collaboration
Science highlights
O3 ended on March 27\textsuperscript{th}, 2020

1 month earlier due to COVID

56 alerts issued during O3
First six months of data analyzed

GWTC-2 released in October 2020

Several exceptional events published

- GW190412: first asymmetric BBH, evidence for higher harmonics
- GW190425: the second BNS merger
- GW190521: a BBH with total mass over 150 times the mass of the Sun
- GW190814: The most asymmetric mass ratio merger ever observed \( (m_1/m_2 = 9) \). The secondary mass of 2.6 Msun lies in the lower ‘mass gap’ \( \Rightarrow \) either the lightest BH or the heaviest NS ever observed!
First observation of NS-BH mergers

**GW200105**
- 8.9 - 1.9 M⊙
- 170 - 390 Mpc
- Livingston-Virgo
- 7700 deg²

**GW200115**
- 5.7 - 1.5 M⊙
- 240 - 400 Mpc
- Hanford-Livingston-Virgo
- 900 deg²
Collaboration organization
The Virgo Collaboration

~690 members, ~450 authors, 126 institutions from 15 countries

33 Groups:
- 29 full members
- 4 in the first year (AUTH, VU, LUTH-CAEN, IFT Madrid)

9 countries represented in the Virgo Steering Committee
Main open points

Apart from the science

- Virgo study
- LVK coordination
- Post-05

Phase I
Commissioning

Phase II
Budget/procurement/TDR
Coating choice
05 starting date

AdV+

Collaboration re-organization

New funding model

Core Program

New bylaws

Virgo & ET
Virgo Organization Committee (VOC)

Toward a new statute for the collaboration
  Phase 1&2: first report released, setting the stage for a new statute
  Moving to Phase 3: drafting the bylaws

Final approval hopefully in fall

Main points addressed:
  Membership
  Governance
  Organization
  Collaboration life
Diversity

Virgo is committed to pursue a policy of inclusion. Several actions put in place so far

Virgo has signed the ECFA/Appec/Nuppec Diversity charter

Diversity Chair permanently invited to Virgo Steering Committee - wide

Diversity session routinely scheduled in Virgo weeks

Increasing attention to gender balance in committees and responsibility roles (e.g. VOC, post-O5 committee)

Still a long way to walk, but strongly motivated to do so
Detector status and plans
Advanced Virgo+ design sensitivity

Phase I: reduce quantum noise, hit against thermal noise. BNS range: 100 Mpc’s
Phase II: lower the thermal noise wall. BNS range: 200 Mpc’s or more
**Advanced Virgo+: content & schedule**

**Two phases project**

**Phase I (before O4 run/2022)**
- Mainly an upgrade to reduce quantum noise: no mirrors change
- Reduction of technical noises
- Preparation of Phase II

**Phase II (before O5 run/2025)**
- More invasive upgrade to reduce thermal noise: mirrors change

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AdV+ Phase I: status
Advanced Virgo+ Phase I
Advanced Virgo+ Phase I
Advanced Virgo+ Phase I
Advanced Virgo+ Phase I

- Laser Upgrade
- Fiber amplifier
- Slave laser
- SR mirror
- Auxiliary lasers
Advanced Virgo+ Phase I

New IMC payload ✔
+ Instrumented baffle ✔

Auxiliary lasers ✔

SR mirror ✔
Advanced Virgo+ Phase I

- New IMC payload
- Instrumented baffle
- SR mirror
- New OMC
- Scattered light mitigation
- New photodiode electronics
- Auxiliary lasers

Diagram showing the components and connections of the Advanced Virgo+ Phase I.
Advanced Virgo+ Phase I

- New IMC payload
- Instrumented baffle
- Laser Upgrade
- 100W Laser
- Input Mode Cleaner
- Faraday Isolator
- PRM POP
- BS
- CP
- WI
- WE
- Auxiliary laser
- Air pressure reduction in CITF
- New OMC
- Scattered light mitigation
- New photodiode electronics
- Output Mode Cleaner
- Photodiode
Advanced Virgo+ Phase I

- New IMC payload ✓
- Instrumented baffle ✓
- HVAC noise reduction ✓
- New OMC ✓
- Scattered light mitigation ✓
- New photodiode electronics ✓
- Laser Upgrade ✓
- Auxiliary lasers ✓
- Air pressure reduction in CITF ✓
- Auxiliary lasers ✓
Advanced Virgo+ Phase I

- New IMC payload ✓
- Instrumented baffle ✓
- HVAC noise reduction ✓
- Laser Upgrade ✓
- SR mirror ✓
- New OMC ✓
- Scattered light mitigation
- New photodiode electronics

- Newtonian Noise cancellation ✓
- Air pressure reduction ✓
- Auxiliary lasers
Advanced Virgo+ Phase I

- New IMC payload
- Instrumented baffle
- HVAC noise reduction
- Laser Upgrade
- SR mirror
- New OMC
- Scattered light mitigation
- New photodiode electronics
- Newtonian Noise cancellation
- Auxiliary lasers
- Air pressure reduction in CITF
- Frequency Dependent Squeezing
Quantum noise reduction system

Goal: use frequency dependent squeezing in AdV+ Phase I
Quantum noise reduction (QNR)

Installation completed!
QNR commissioning started in April
AdV+ Phase I: status today

The installation of the main interferometer was completed in December 2020.
The commissioning of the main interferometer started in January 2021.

- 3km arms locked with green beams 😊
- Central interferometer locked with infrared beam 😊
- Next: lock of the entire ITF

Installation of QNR has been completed in April 2021.
The commissioning of QNR started in May 2021.

- Filter cavity aligned and locked with the green beam
**AdV+ Phase I: next steps**

**Interferometer locking**
- Locking at 25 W: June (some delay on this task)
- Locking at 40 W: July-August

**QNR commissioning**
- First squeezing dependent measurement: August
- Completion of QNR integration with ITF: Fall
AdV+ Phase I: next steps

After interferometer locking
- Interferometer optical characterization
- Interferometer optical tuning
- Scattered light mitigation
- Noise hunting
  » First without QNR
  » Then with QNR

Preparation for O4

June 2022: Start of O4
- LIGO-Virgo-KAGRA discussions ongoing: start of O4 might be delayed by a couple of months
AdV+ Phase I: noise hunting

Most of noise hunting is about investigating the effect of technical noises

List of potential technical noises updated
  Organized by system and subsystems
  132 entries

Responsible for each technical noise identified

Next steps
  Collect documentation and task sheets for each technical noise
  Prepare noise hunting plan
AdV+ Phase II: status
Main changes

Larger beams on end test masses
  » 6 cm radius ⇒ 10 cm radius

Larger end mirrors
  » 40 kg ⇒ 100 kg

Better mirror coatings
  » Lower mechanical losses, less point defects, better uniformity

New suspensions/seismic isolators for large mirrors

Further increase of laser power
  » 40W ⇒ 60W ⇒ 80 W
Mirrors

Project schedule imposed by mirror production (high risk)

Constrained by budget availability
Mirrors

Status

Substrates acquired and received at LMA 😊
Call for tender for the mirrors polishing now starting at CNRS (EGO could not do it)
Several upgrades at LMA needed to prepare the realization of the mirrors
Coordination with LIGO
AdV+ and A+ will implement a common low-CTN coating formulation
AdV+ and A+ will make a coating selection together in June-July

Two candidates left
SiN/SiO₂
Ti:GeO/SiO₂

Both performing well in terms of mechanical losses

Absorption is the critical parameter
Ti:GeO/SiO₂ multilayer gives 3-4 ppm
Measurement on SiN/SiO₂ multilayers not available yet

Decision to be made during the summer
Super Attenuators and Payloads for Large End Mirrors

Development of blades springs and anti-magnetic springs for super-attenuators started
Construction of large payload prototype started

Goals:
Design by the end of the year
Construction in 2022-2023
Installation from mid-2023 (at the end of O4)
Other upgrades for Phase II

Main actors apart from mirrors and suspensions (in terms of budget)

- Vacuum
- Thermal compensation system
- Detection
- Injection
- Pre-stabilized laser
- Instrumented baffles

List of deliverables for AdV+ Phase II available

Writing of TDR and of its review started
AdV+ Phase II schedule

About two years left to complete the construction of the AdV+ Phase II

We are here
Beyond AdV+?
Beyond AdV+?

Breaking news!

June 30, 2021

The European Strategy Forum on Research Infrastructures (ESFRI) decided to include the Einstein Telescope (ET) in the update of its roadmap for 2021.
Beyond AdV+?

O5 will end in 2026. ET will not start taking data before 2036

There is at least 1 decade to be covered by 2G+(++)

There will be room for improving the detector after AdV+ and reach the ultimate infrastructure limits

The discussion ahead:
- Scenarios for improving Virgo (science, technologies, timing, costing)
- Needed R&D
- Perspective in the context of 3G advent
Beyond AdV+?

Post-O5 Committee


Charge - pursue a preliminary study of the viable scenarios for upgrading Virgo beyond the AdV+ program. The study should assess:

The options for design choices and technology implementation which promise to improve the sensitivity or the robustness of the detector and give an estimate of their gain;
The sensitivity which could be achieved for different investment scenarios;
The technical readiness of the various options and the R&D perspectives;
The scientific case for the various scenarios.

To be coordinated with LIGO and KAGRA: towards a "Post-O5 network" debate
Conclusion

A lot of science out of O3!
First observation of NS-BH mergers

The Virgo collaboration is growing

Detector

AdV+ Phase I (for O4)
» Installation of AdV+ Phase I completed!
» Commissioning/locking of interferometer progressing

AdV+ Phase II (for O5)
» Design progressing
» Substrates received, call for tender for mirrors polishing launched
» Coating decision to be made soon

Post-O5
» Committee settled up, coordination with LIGO and KAGRA necessary