Prospective study of Virgo's impact in sky localisation of GW events within the LVK network for O5

October 14th, 2025 – GDR Ondes Gravitationnelles

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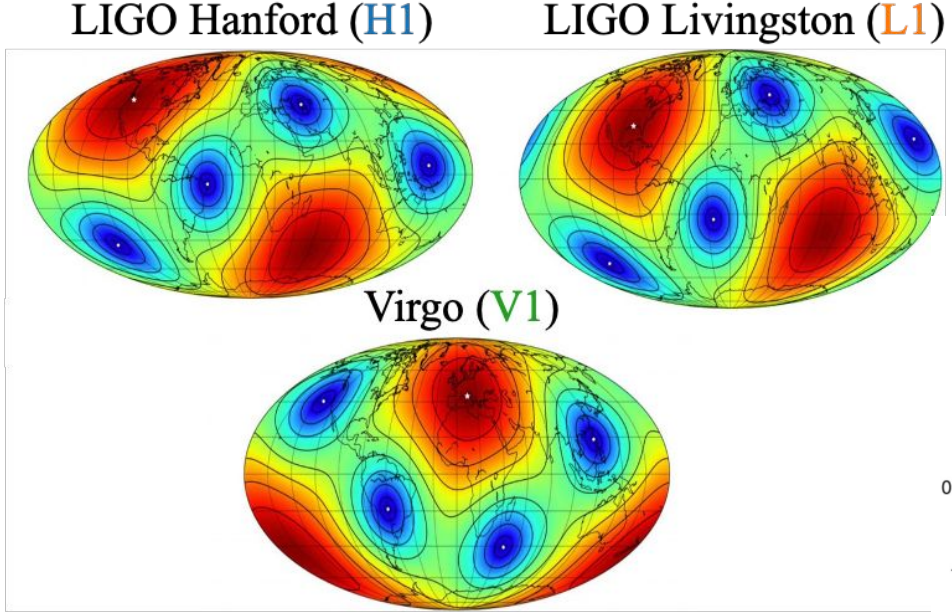
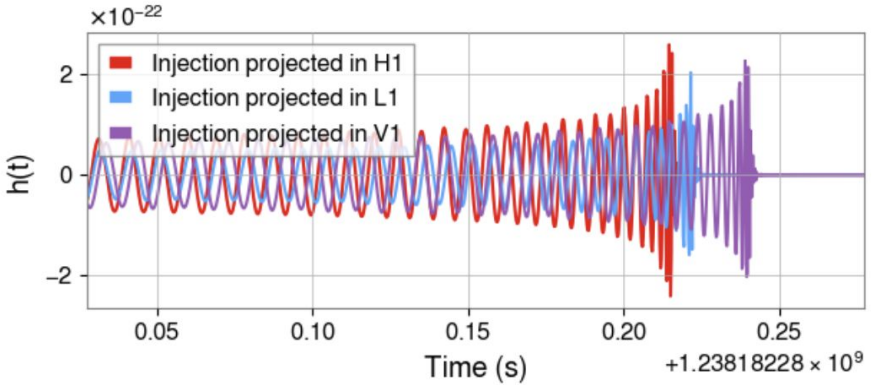
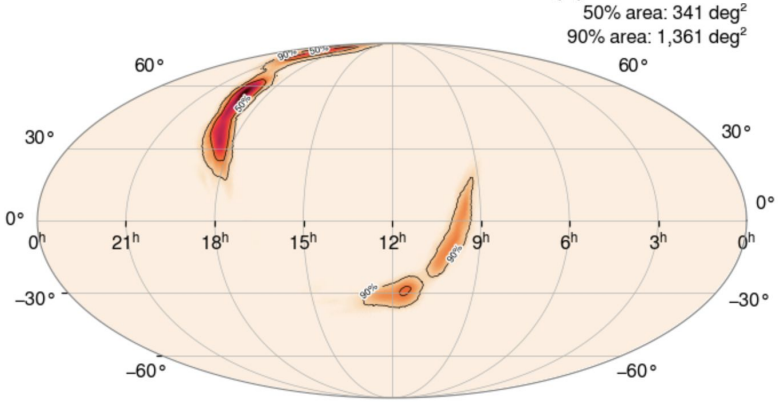
Data analysis and sky localization





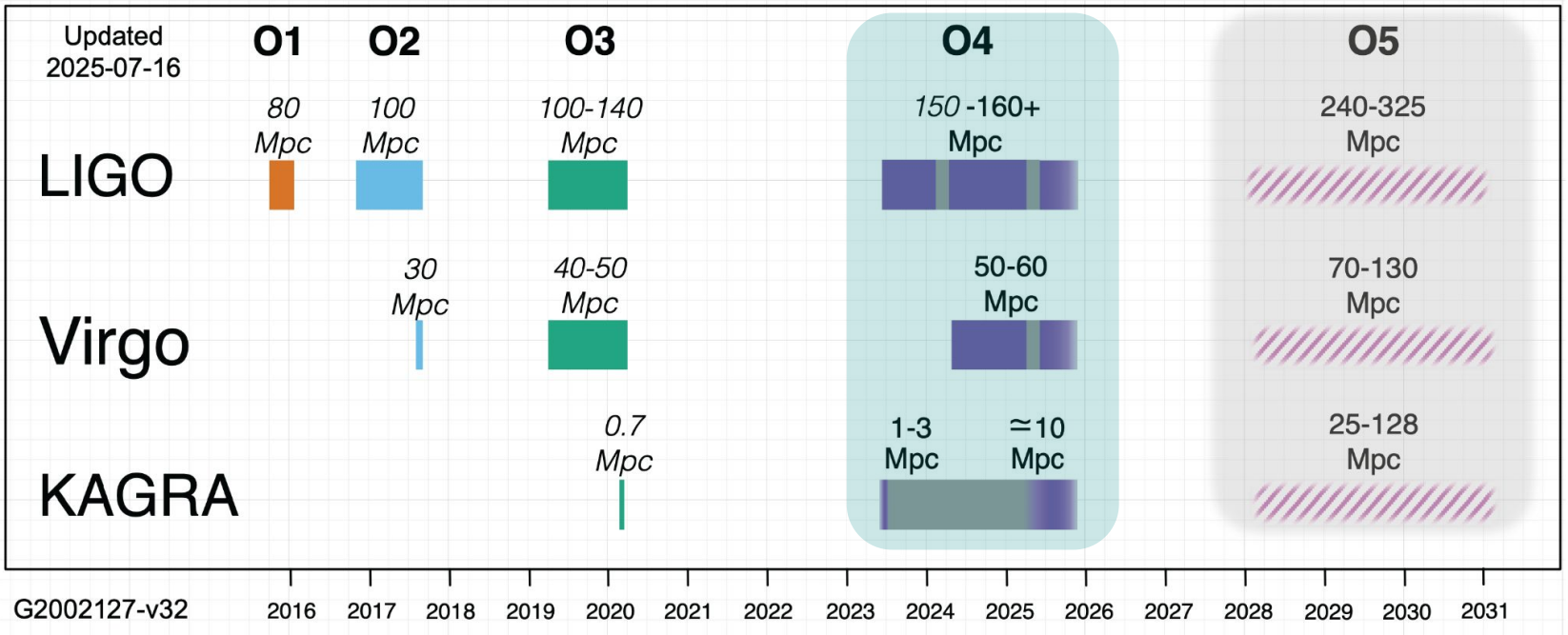


BAYESTAR [PhysRevD.93.024013]

Context

→ Virgo joined the run later with a lower sensitivity than the LIGOs

→ How much does it contribute to the sky localisation of transients?

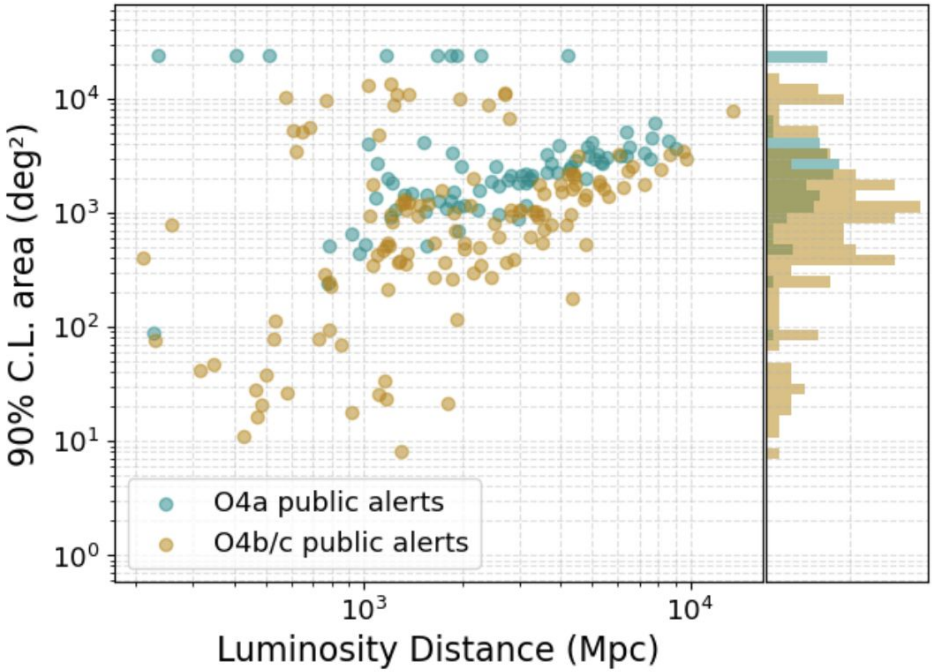


Impact of Virgo in the current O4 run

Virgo did not join the first part of the run (O4a) but joined for the second and third parts (O4b - O4c)

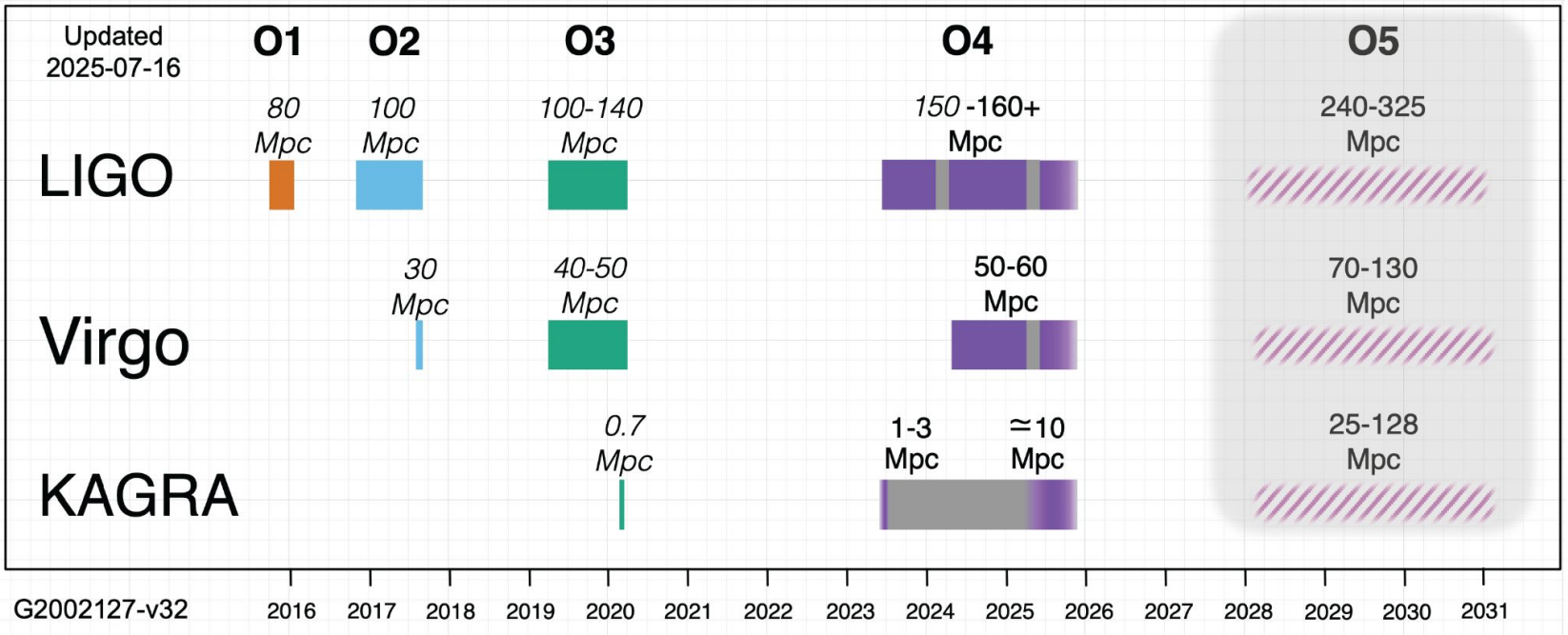
From public alerts : median of 90% C.L area improved

From internal study : 10% of the O4b and O4c alerts see their sky localization improved by a factor 10 thanks to the inclusion of Virgo data.



Future observation run

→ Uncertainties remaining regarding the LIGO, Virgo and KAGRA O5 status and project upgrades



Future observation run

- Study on a realistic simulation campaign
- Focus on LIGO and Virgo
- Different O5 upgrades scenarios considered
- Purpose: estimate the impact of Virgo for detection and multi-messenger astronomy

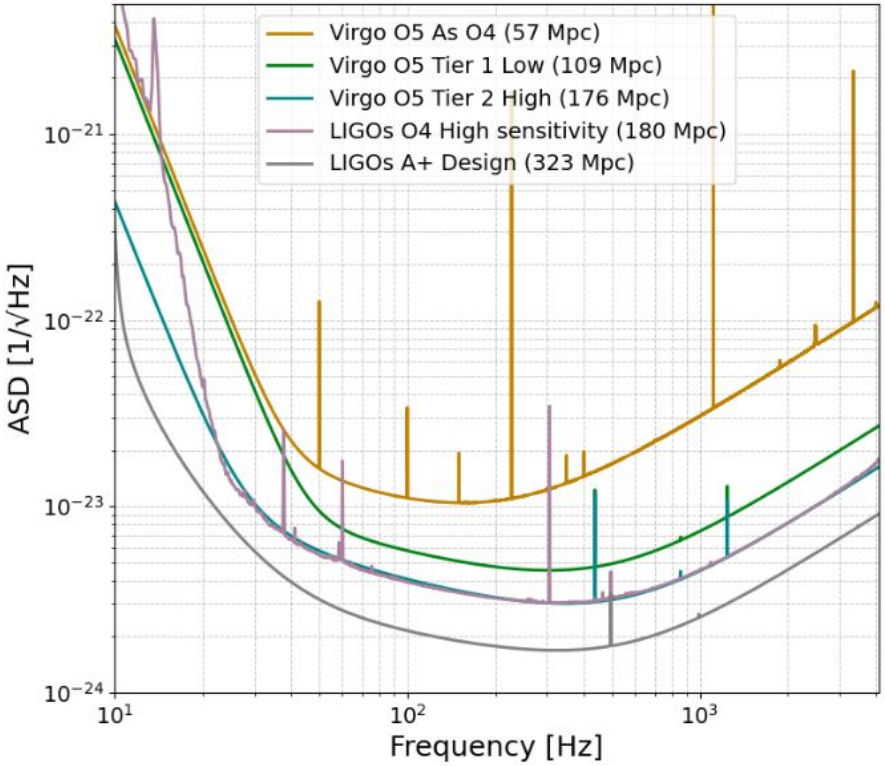
Simulation setup

→ GW simulated signals follow a distribution uniform in differential comoving volume per unit proper time

→ Rates from GWTC-4 (O4a) BGP (110 $Gpc^{-3}yr^{-1}$)

→ Mass spectrum from GWTC-3 (O3)

→ Gaussian noise from the different scenarios' ASDs



Virgo's impact on expected number of detections

Median # events per year with H1L1V1 network

Median # events per year with H1L1 network

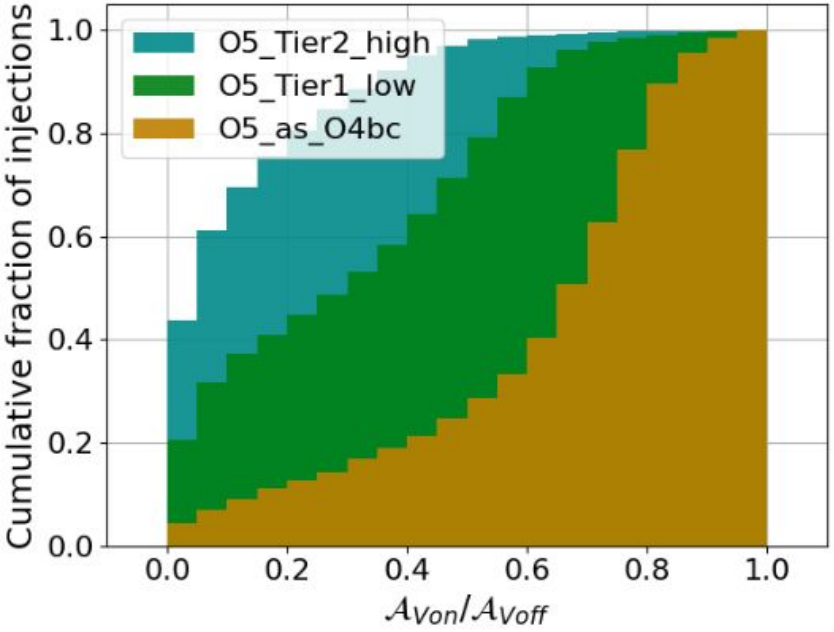
H1 and L1	V1	BNS	NSBH	BBH
A+	O4	1.2	1.1	1.1
A+	Tier 1 Low	1.2	1.2	1.2
A+	Tier 2 High	1.3	1.3	1.2
O4 High	O4	1.3	1.3	1.2
O4 High	Tier 1 Low	1.4	1.7	1.3
O4 High	Tier 2 High	1.8	2.0	1.7

⚠️ CAVEAT ⚠️

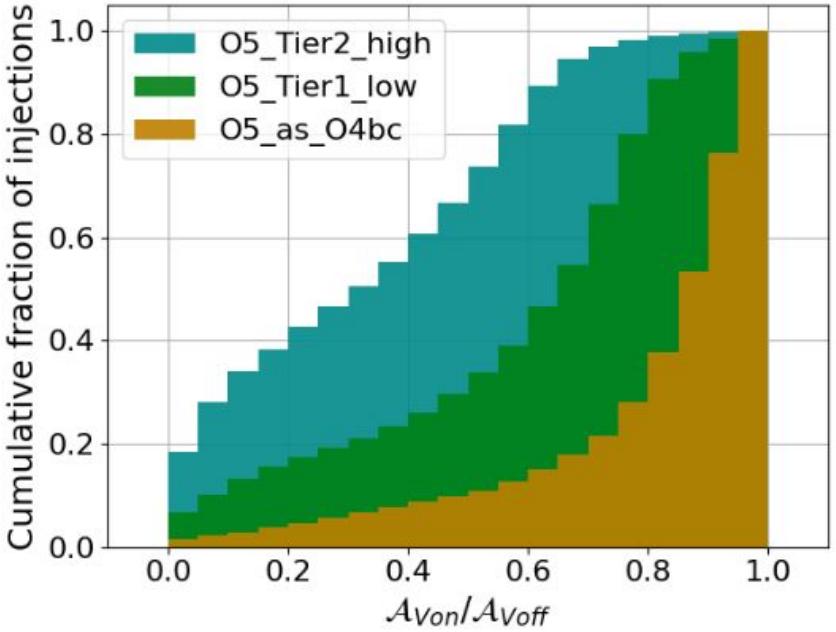
- Mass spectrum from GWTC-3
- Table gives relative number of detections
  - With Virgo VS without Virgo
  - If LIGO upgrades to A+ design (from 180 Mpc to 323 Mpc BNS range)
    → **expect 5x more detections**

Virgo's Impact on the Sky Localization

2 LIGOs at O4 high design



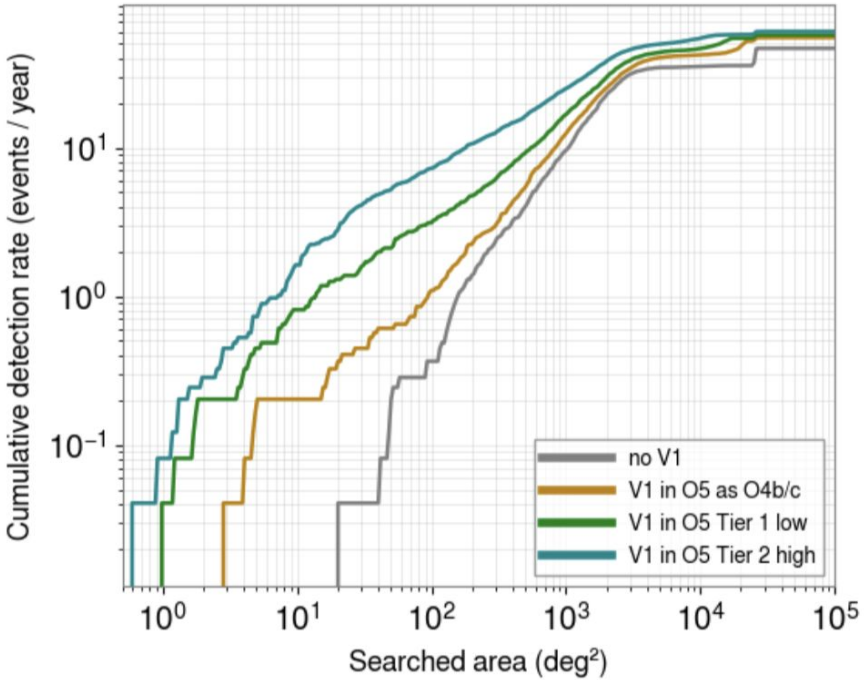
2 LIGOs at A+ design



90% containment area with Virgo / 90% containment area without Virgo

Focus on BNS

2 LIGOs at A+ design (BNS range at 323 Mpc)



Keep only simulated events with both component masses ‹ 3M⊙(**BNS mergers**)

Searched area = minimal area to search before finding the true sky localisation of the GW event

⚠️CAVEAT ⚠️

- Detection criteria is simplistic
- Total number of expected detections is optimistic ⟶ Focus on the relative trend

Summary and conclusion

- Prospects for CBC detection and multimessenger analysis in different O5 scenarios
- Some sensitivities are optimistic and observing scenarios are approximate
- Even with a lower sensitivity, Virgo has a non negligible impact on sky localization of CBCs in O4
- If the Virgo-LIGO sensitivity gap becomes too large, Virgo impact might become marginal
- Upgrading both Virgo and LIGO detectors maximizes the chances of detecting a well localized BNS

Backup Slides

Expected annual number of detections

Run	BNS	NSBH	BBH
A+ And No V1	46^{+58}_{-27}	8^{+12}_{-7}	280^{+330}_{-150}
A+ And V1 As In O4	54^{+68}_{-32}	9^{+14}_{-7}	310^{+370}_{-170}
A+ And V1 Tier1 Low	57^{+70}_{-34}	9^{+14}_{-7}	320^{+380}_{-180}
A+ And V1 Tier2 High	60^{+74}_{-35}	11^{+15}_{-8}	340^{+410}_{-190}
O4 High And No V1	8^{+12}_{-7}	1^{+3}_{-1}	77^{+94}_{-44}
O4 High And V1 As In O4	10^{+15}_{-8}	1^{+4}_{-1}	91^{+112}_{-52}
O4 High And V1 Tier1 Low	12^{+16}_{-9}	1^{+5}_{-1}	101^{+123}_{-57}
O4 High And V1 Tier2 High	15^{+21}_{-10}	2^{+5}_{-2}	127^{+154}_{-72}

→ GW simulated signals follow a distribution uniform in differential comoving volume per unit proper time

- Detection = Network SNR › 8
- IFO contributed to the detection and localisation if SNR_{ifo} › 1

→ Gaussian noise from the different scenarios' ASDs

→ Assumed duty cycle: independent, 70% for all IFOs

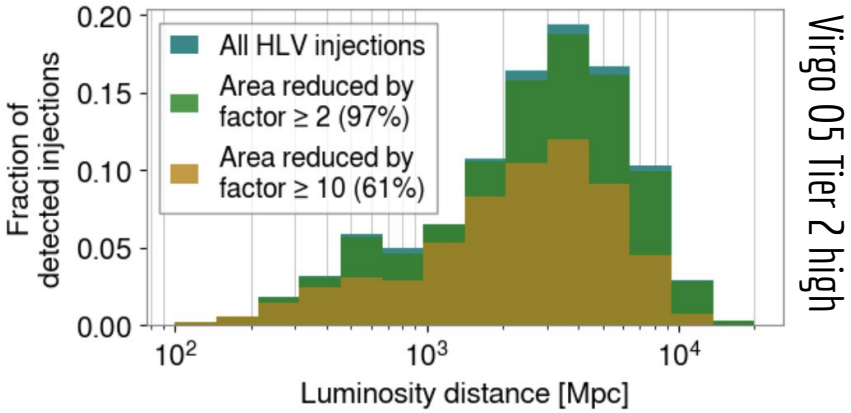
→ Rates from GWTC-4 (O4a) BGP (110 $Gpc^{-3}yr^{-1}$)

→ Mass spectrum from GWTC-3 (O3)

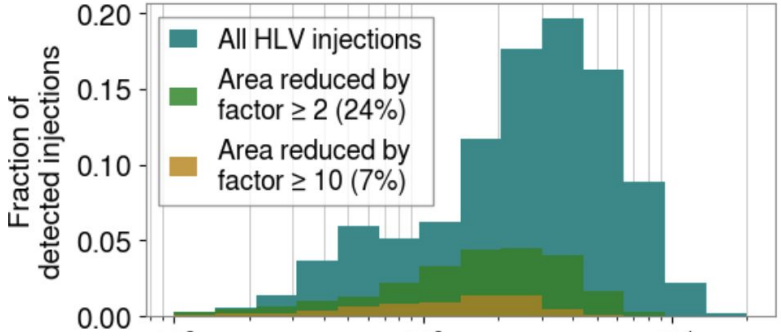
Virgo's Impact on the Sky Localization

2 LIGOs not upgraded (BNS range at 180 Mpc)

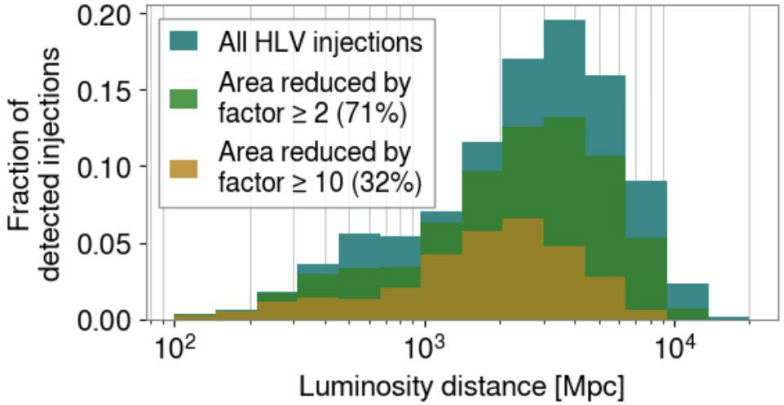
Considering only simulated events detected by **all the three detectors ("HLV injections")**
Localize an injection with and without Virgo data
All types of sources (**BBH, NSBH and BNS**)



Virgo O5 Tier 2 high



Virgo as O4



Virgo O5 Tier 1 Low

Virgo's Impact on the Sky Localization

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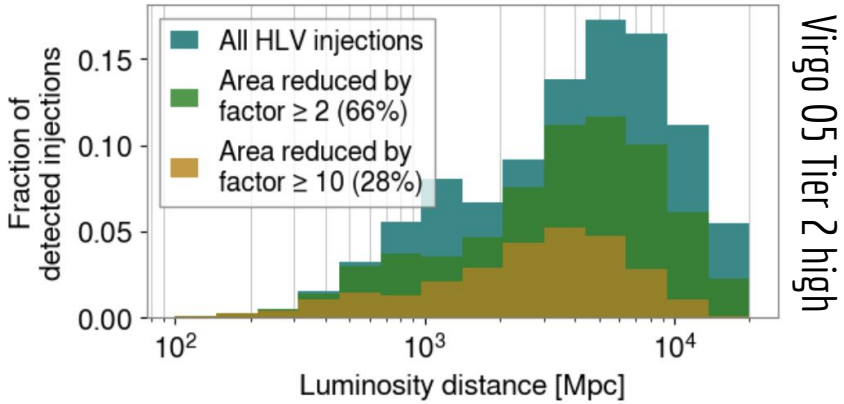
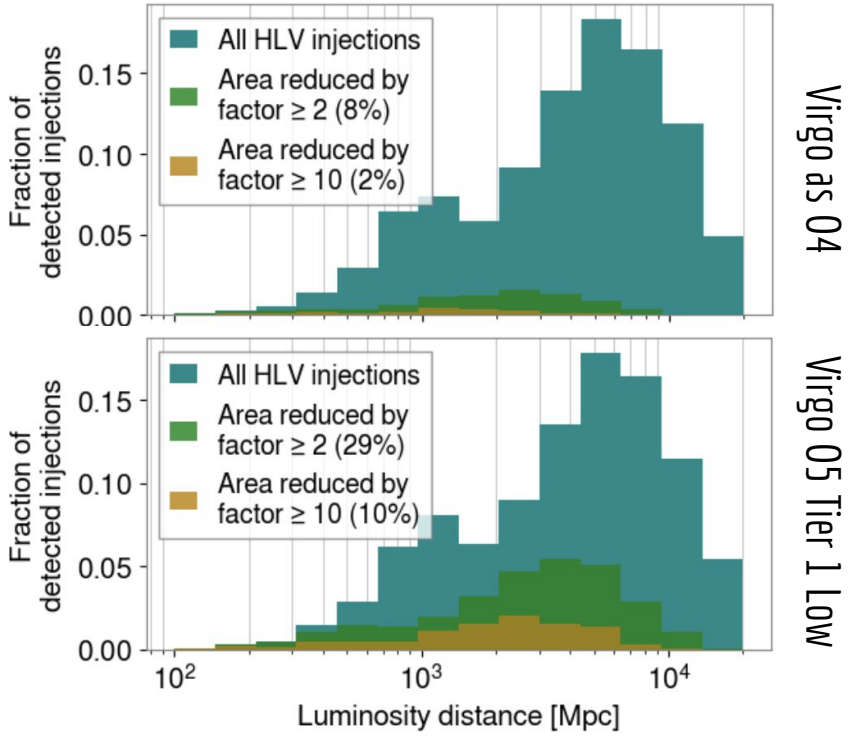
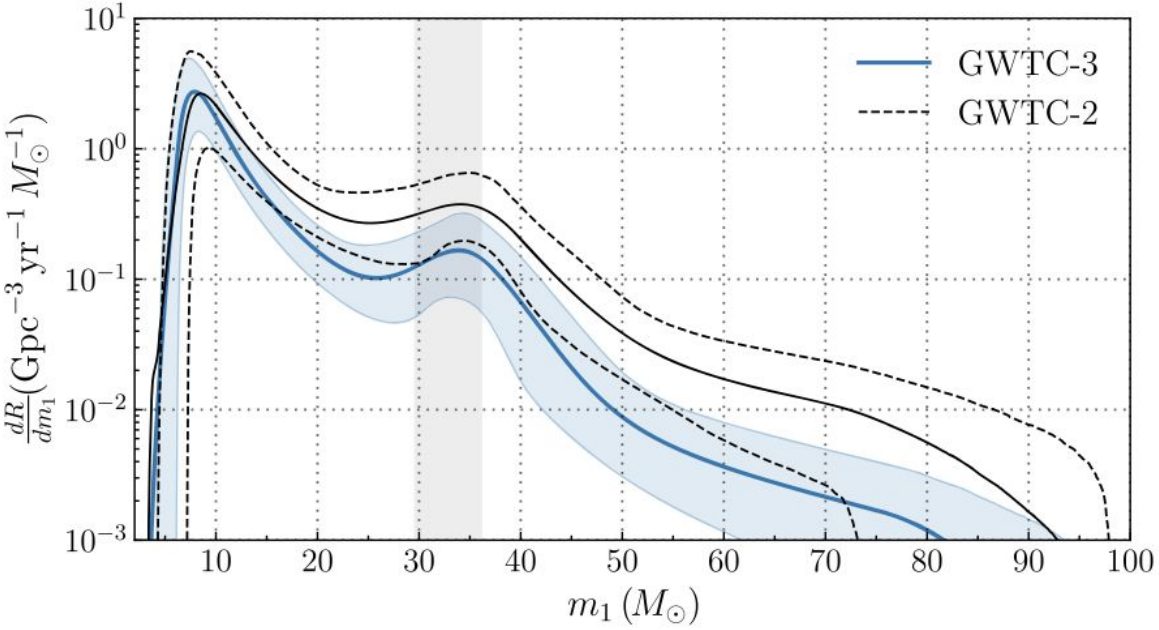
Localize an injection with and without Virgo data
All types of sources (**BBH, NSBH and BNS**)





Mass model for the simulation



From [PhysRevX.13.011048]

→ Population model inferred from GWTC-3 observations

→ Not the latest result (see the new GWTC-4 population paper [arXiv:2508.18083])