Status Post-O1: Sources, Rates, and Localization

LIGO DAWN II – Thursday, June 7, 2016

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LIGO-G1601468-v5

I. SOURCES: BBH vs. NS BINARIES

GW150914: **first light**

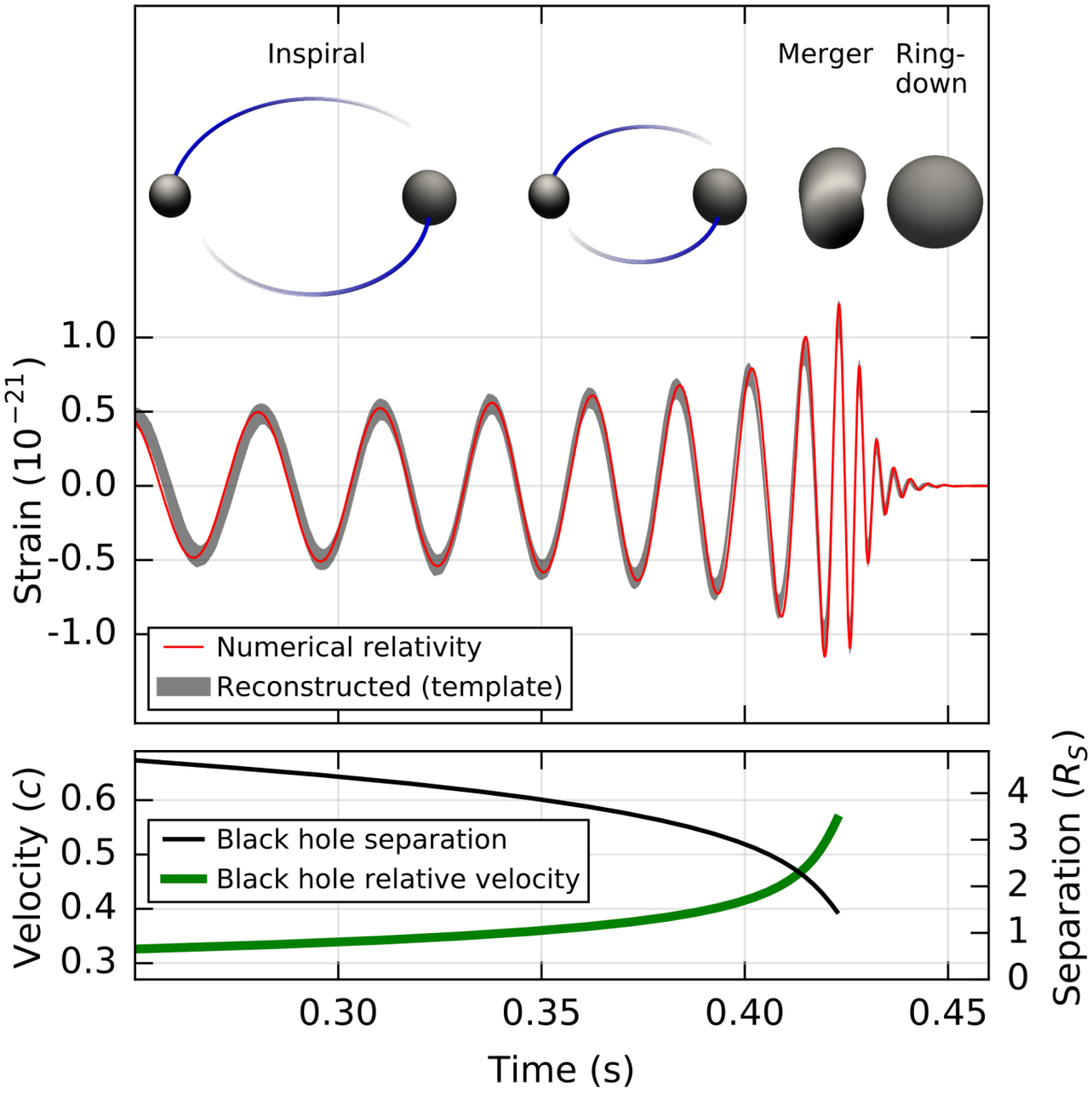


image: LVC 2016, PRL, arXiv:1602.03837

- **Surprising properties…**
  Masses: 36 + 29 → 62 $M_\odot$
  3 $M_\odot$ radiated in GWs!

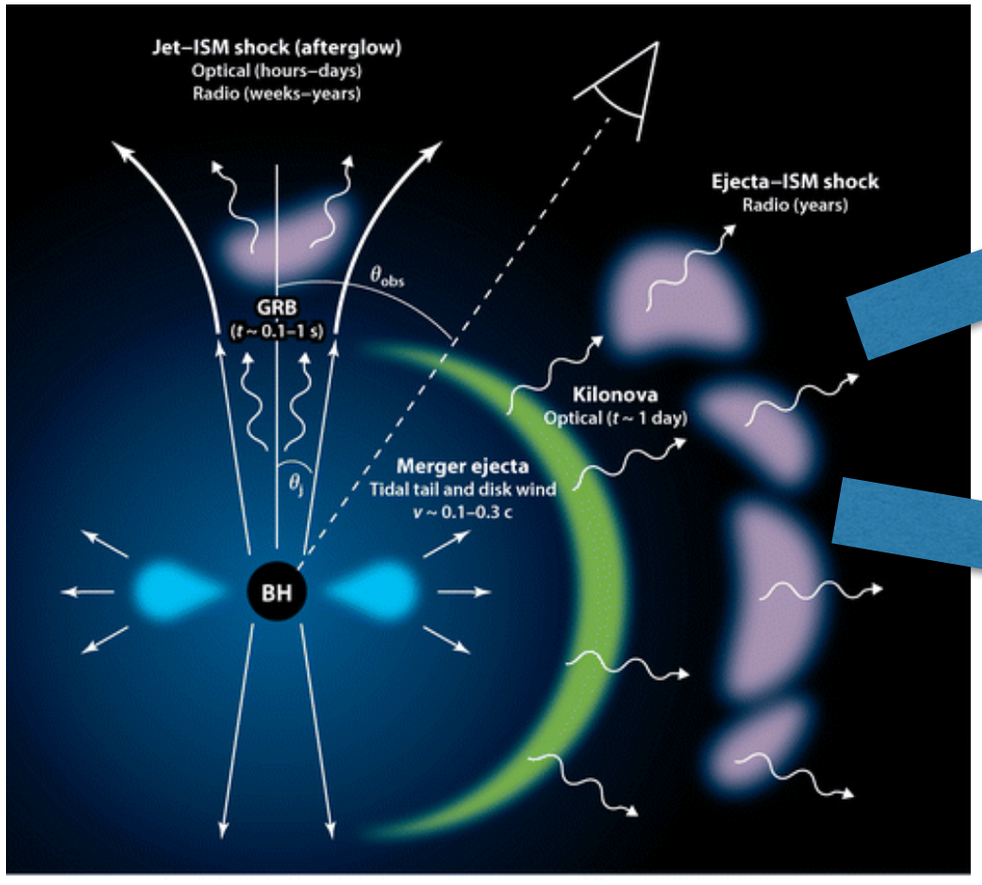
  much heavier than BHs known in X-ray binaries → low-metallicity formation scenario

  Spins weakly constrained, but **nowhere near maximal**:
  <0.7 + <0.9 → ~0.6

- Distance: ~400±200 Mpc, z~0.09

- **Stringent tests** of general relativity…
  Best ever measurement of graviton mass: m_g<10^{-22} eV

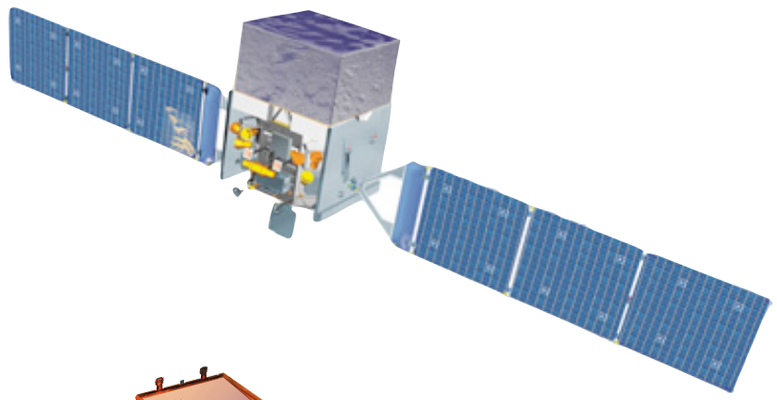
The future is ***bright!***

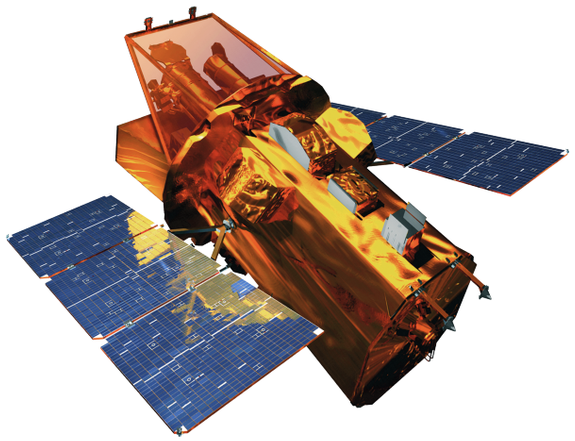


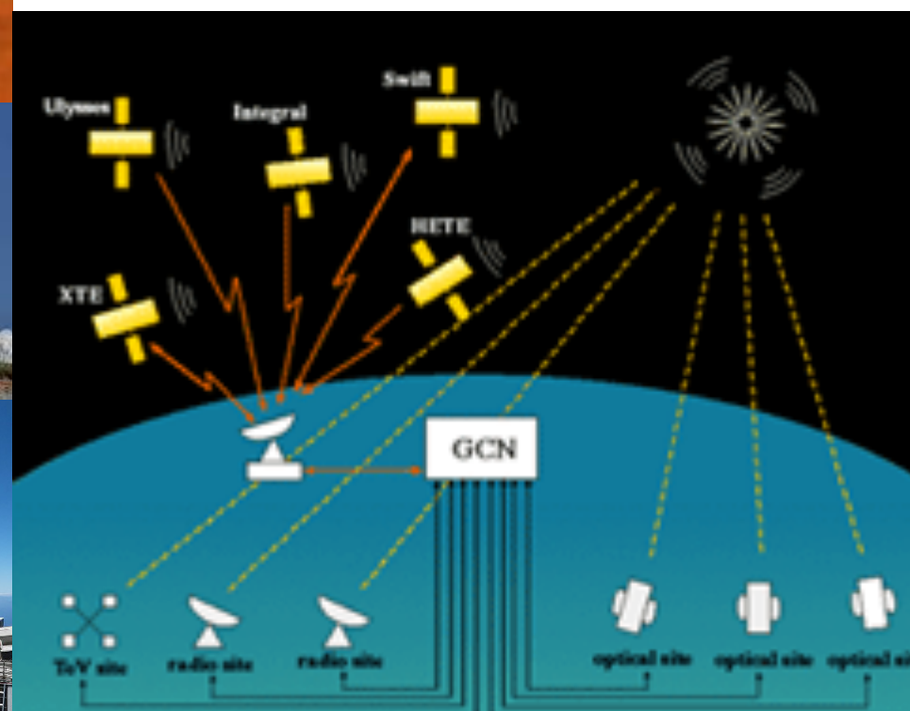
Berger E. 2014.
Annu. Rev. Astron. Astrophys. 52:43–105

- **EM counterparts of LIGO sources**
- **Central engine** vs. **external fireball** and ejecta
- **Pinpoint host galaxy**, determine formation environment
- **Standard sirens**: Calibration-free rung on cosmological distance ladder
- Explain cosmic abundance of heavy elements – **“bling nova”**
- Explain **nature of short GRBs**
- …and (uh oh): challenge whether stellar BBHs are truly barren of matter!

Understanding **the full astrophysical richness of compact binaries** will take not just LIGO, but the broad astronomy community across many wavelengths!

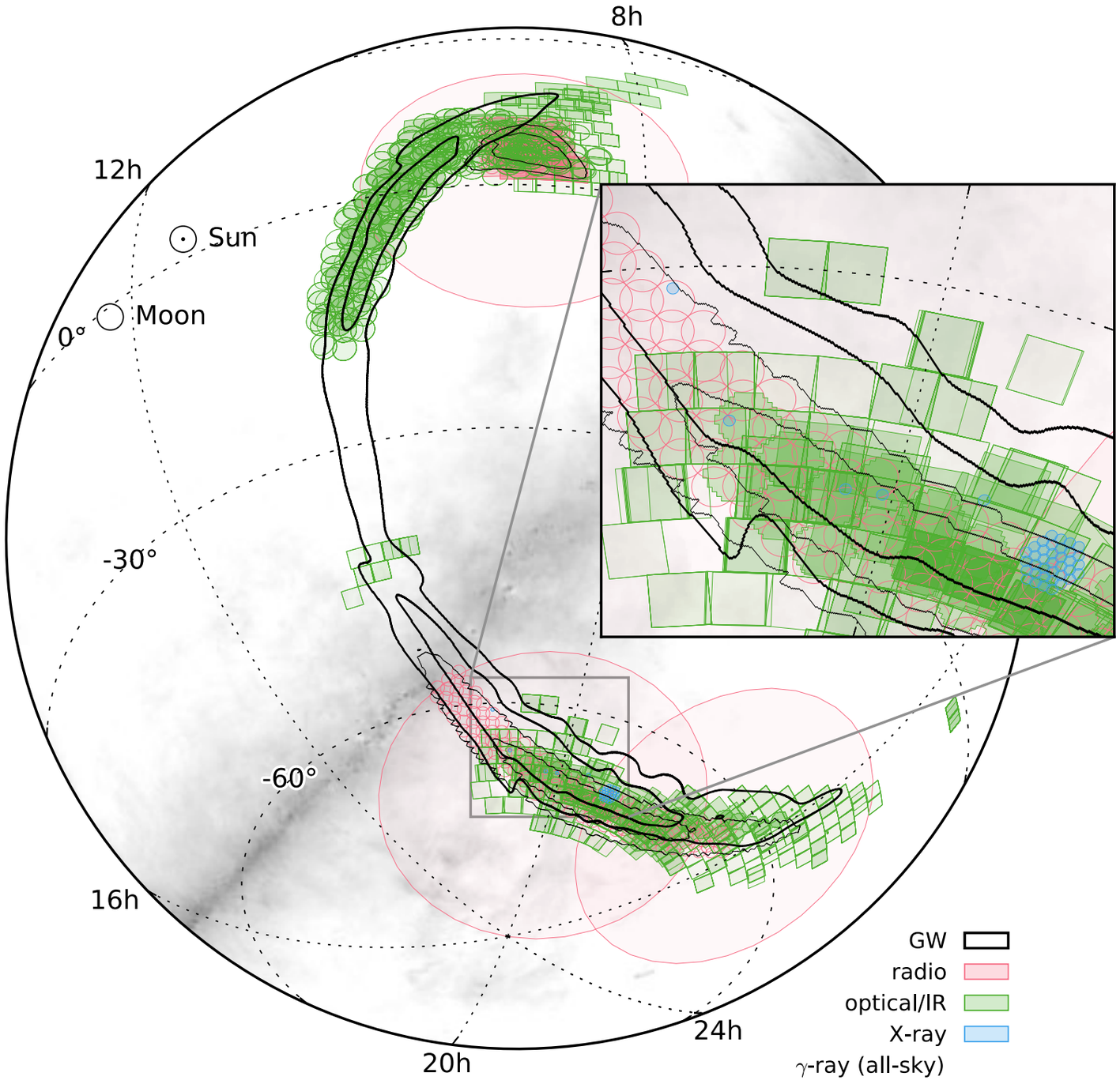





Ulysses
Integral
Swift
HETE
XTE
GCN
TeV site
radio site
radio site
optical site
optical site
optical site

LOCALIZATION AND BROADBAND FOLLOW-UP OF THE GRAVITATIONAL-WAVE TRANSIENT GW150914

LVC+ 2016,
ApJL, in press
arXiv:1602.08492



SELECTED HIGHLIGHTS **from O1 localization + follow-up campaign**

- **Prompt, consistent localization of the first LIGO signal**
  (although LIGO/Virgo alert sent two days late)

- **Possible γ-ray transient** (*Fermi* GBM, though not seen by *INTEGRAL* SPI-ACS)
  Connaughton+ 2016, Savchenko+ 2016

- **Follow-up of nearby galaxies with *Swift* XRT**
  Evans, Kennea, Barthelmey+ 2016

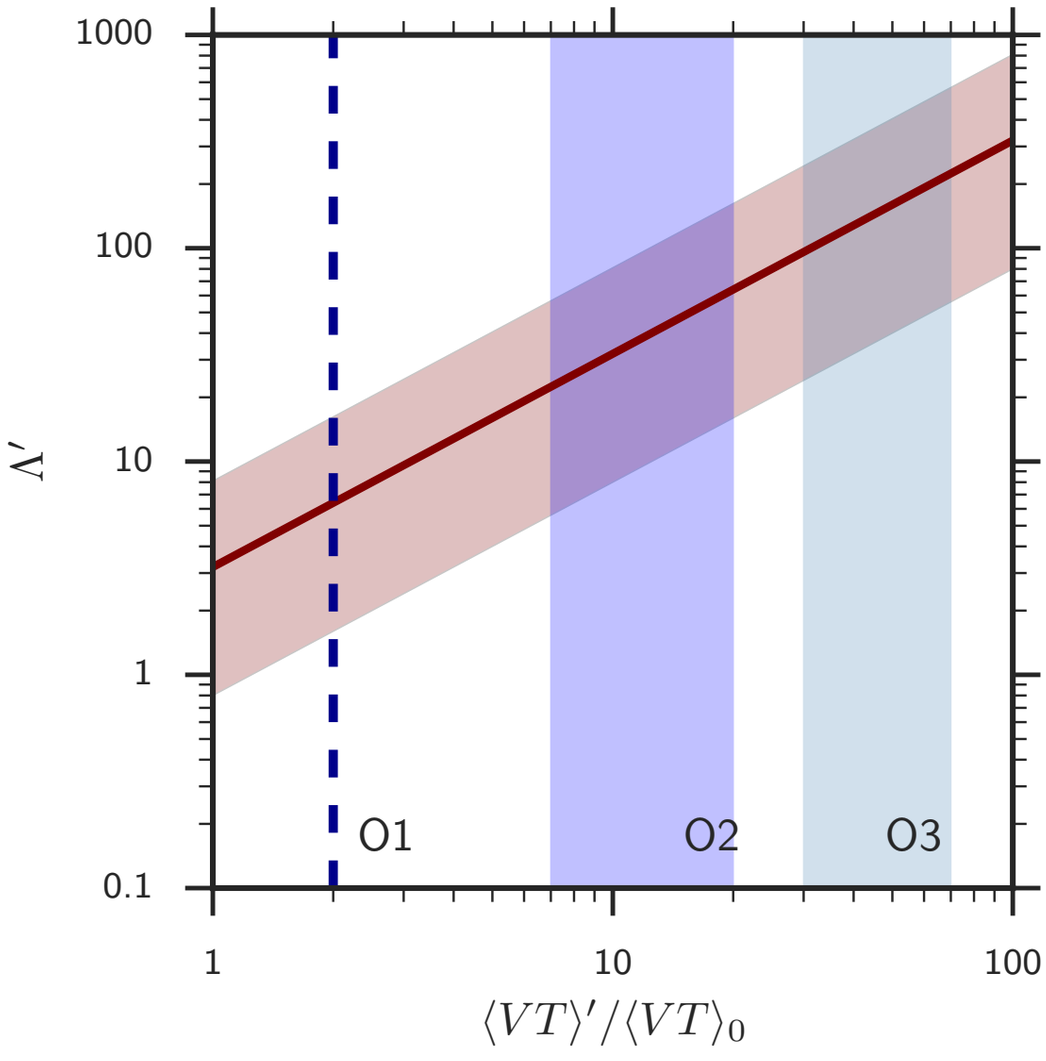
- **DECam search for failed missing supergiants/failed SN** in LMC
  Annis+ 2016

- **Keck spectroscopy of iPTF candidates <1 hr after discovery images; superluminous supernova** discovered in iPTF follow-up
  Kasliwal, Cenko, Singer+ 2016

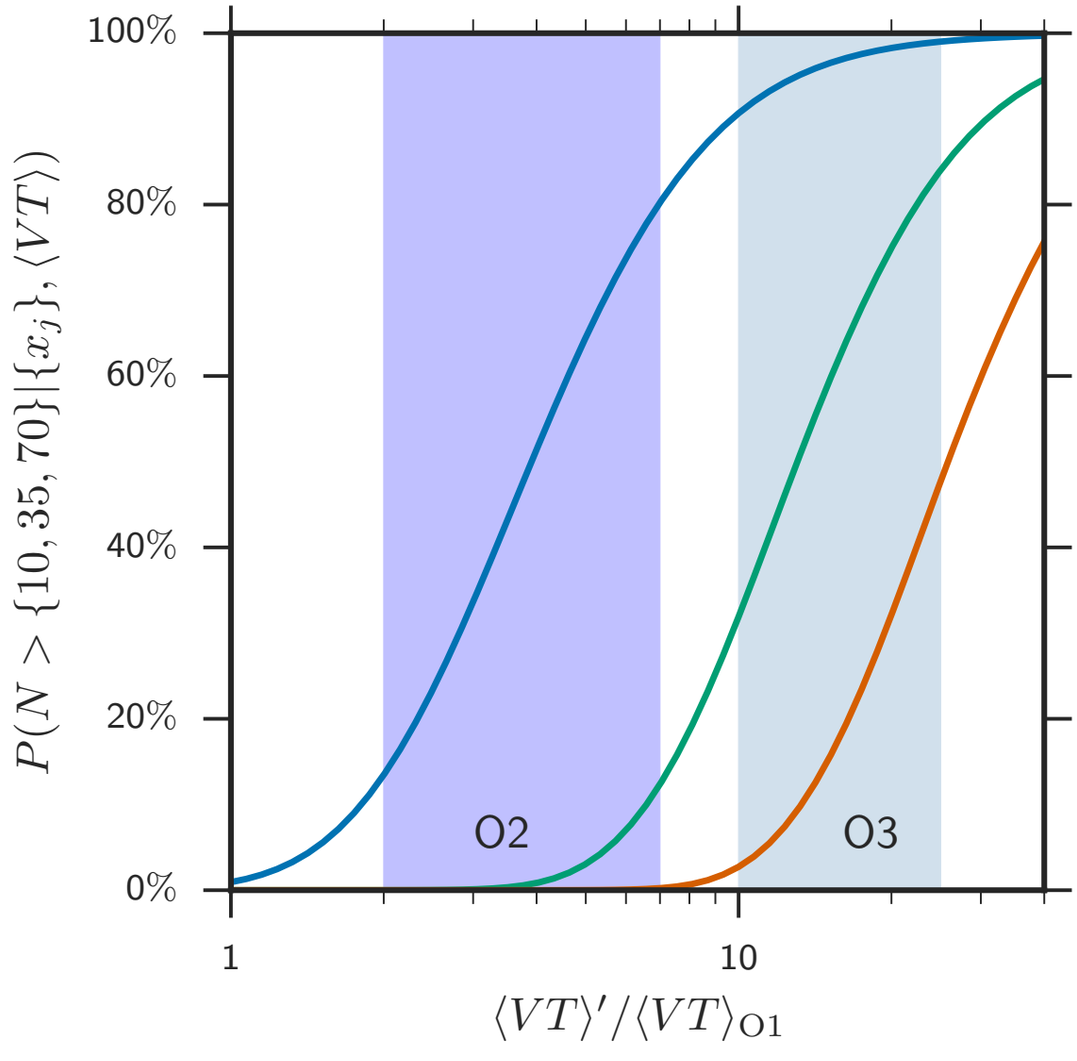
- **DECam** (Soares-Santos+), ***AGILE*** (Tavani+), ***XMM*** (Troja+), ***Fermi* LAT** (LAT Collab.), **Pan-STARRS/PESSTO** (Smartt+), +**many more** in preparation

II. RATES

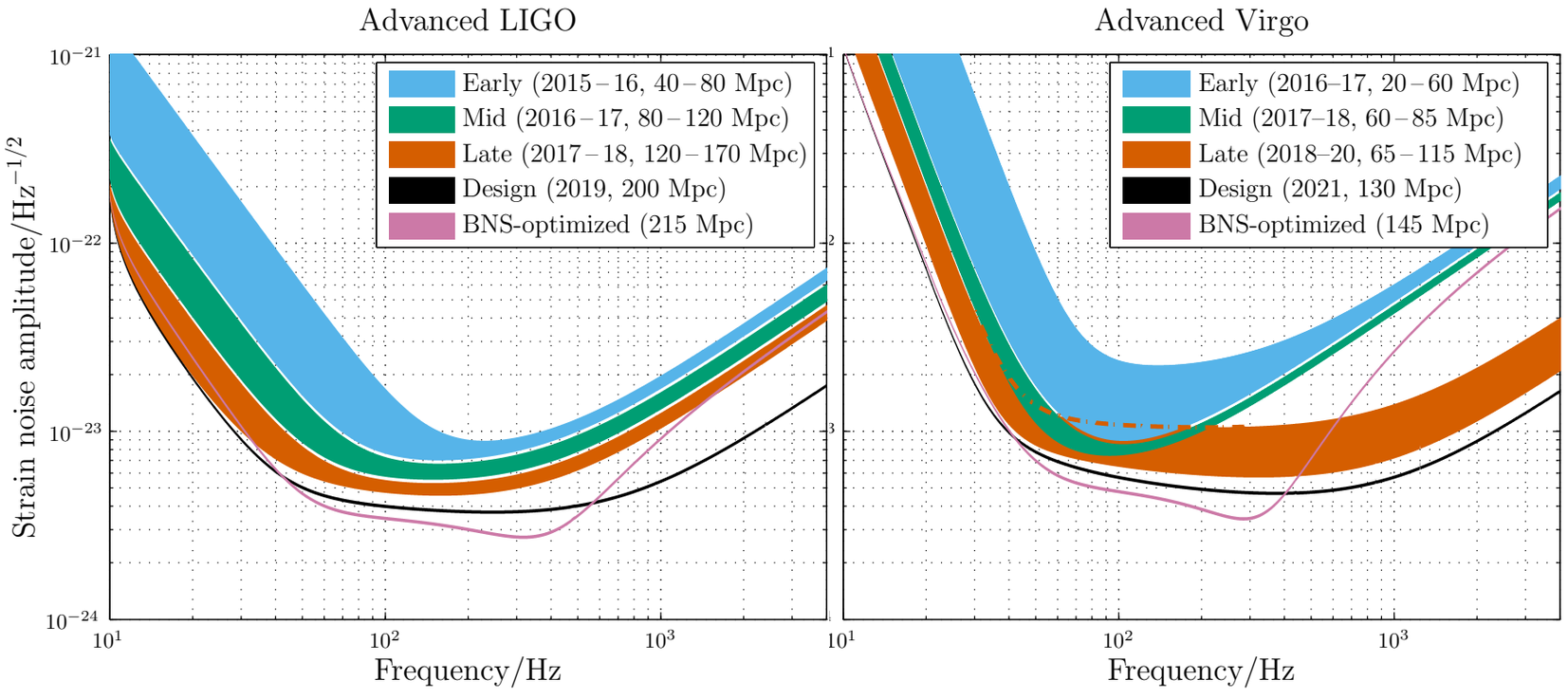
BBH rates:
~10 by O2, ~10–100 by O3



Based on GW150914 alone.
LVC 2016, PRL, arXiv:1602.03842



Based on all O1 events.
LVC 2016, arXiv:1606.04856



BNS/NSBH: same story as Observing Scenarios document.

Detections or astrophysically interesting rate constraints by O2/O3.

Epoch			2015–2016	2016–2017	2017–2018	2019+	2022+ (India)
Estimated run duration			4 months	6 months	9 months	(per year)	(per year)
Burst range/Mpc		LIGO	40–60	60–75	75–90	105	105
		Virgo	—	20–40	40–50	40–80	80
BNS range/Mpc		LIGO	40–80	80–120	120–170	200	200
		Virgo	—	20–60	60–85	65–115	130
Estimated BNS detections			0.0005–4	0.006–20	0.04–100	0.2–200	0.4–400
90% CR	% within	5 deg^2	< 1	2	*> 1–2*	*> 3–8*	*> 20*
		20 deg^2	< 1	14	*> 10*	*> 8–30*	*> 50*
	median/deg^2		480	230	—	—	—
searched area	% within	5 deg^2	6	20	—	—	—
		20 deg^2	16	44	—	—	—
	median/deg^2		88	29	—	—	—

III. LOCALIZATION

Transition to three detectors

- Commissioning of Virgo, KAGRA, and LIGO-India are staggered compared to LIGO timetable (see Lisa Barsotti's talk)

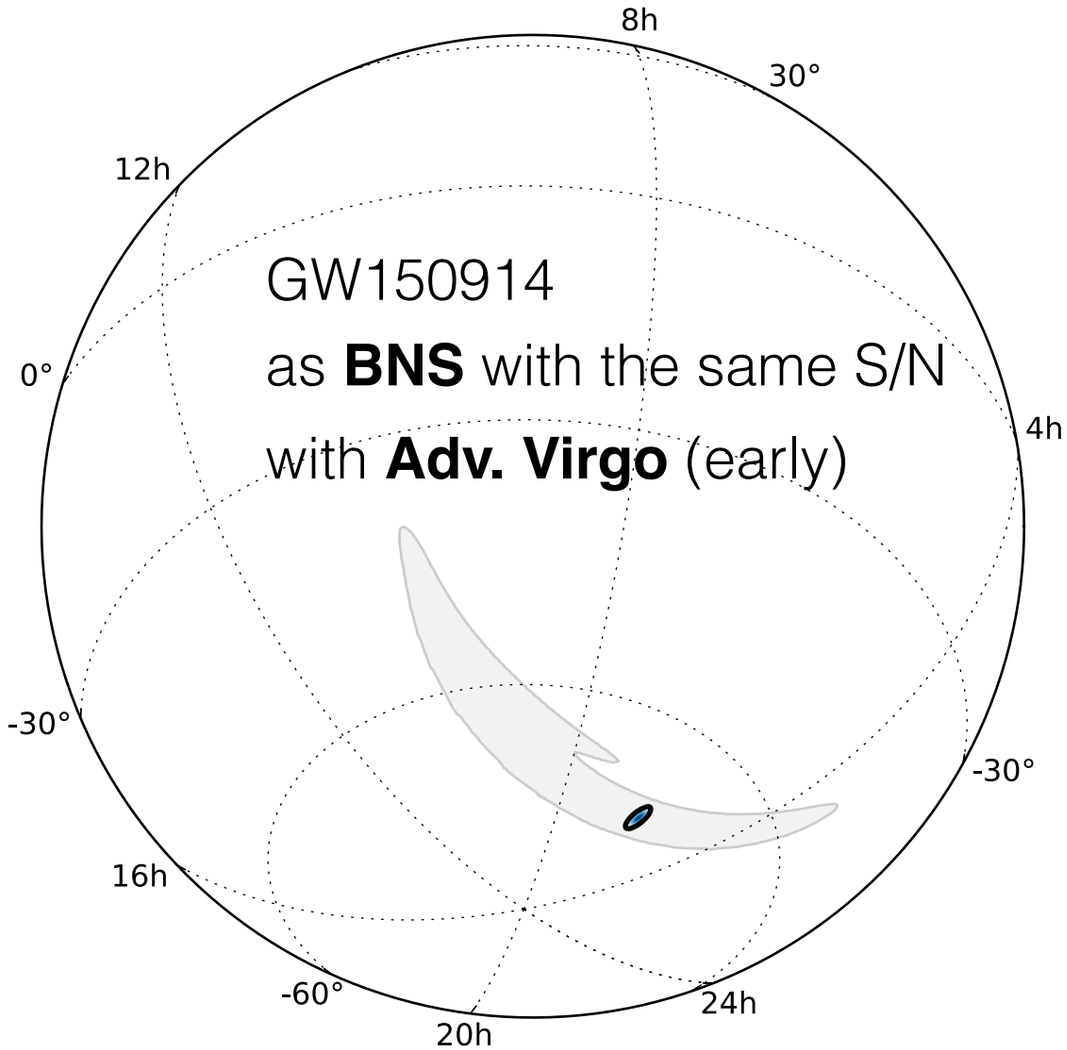
- We will experience a transition where *detection rate* is driven by one pair of detectors but *sky localization* is driven by a third detector.

- Similar transitions may occur with the first third-generation detectors.

- Impact on a given event depends on sky localization and S/N.

- The *average* or *typical* impact of a third detector will depend on its relative sensitivity. At what ratio of sensitivities does the threshold occur? Is it a sharp or a smooth transition?

THE NEED FOR **Advanced Virgo**



Even with“early” sensitivity, Advanced Virgo can **fundamentally transform** the character of GW observations.

Area (deg^2)	GW 150914	NSBH	NSNS
HL	400	300	200
HLV	11	11	5
HLI	6	7	4

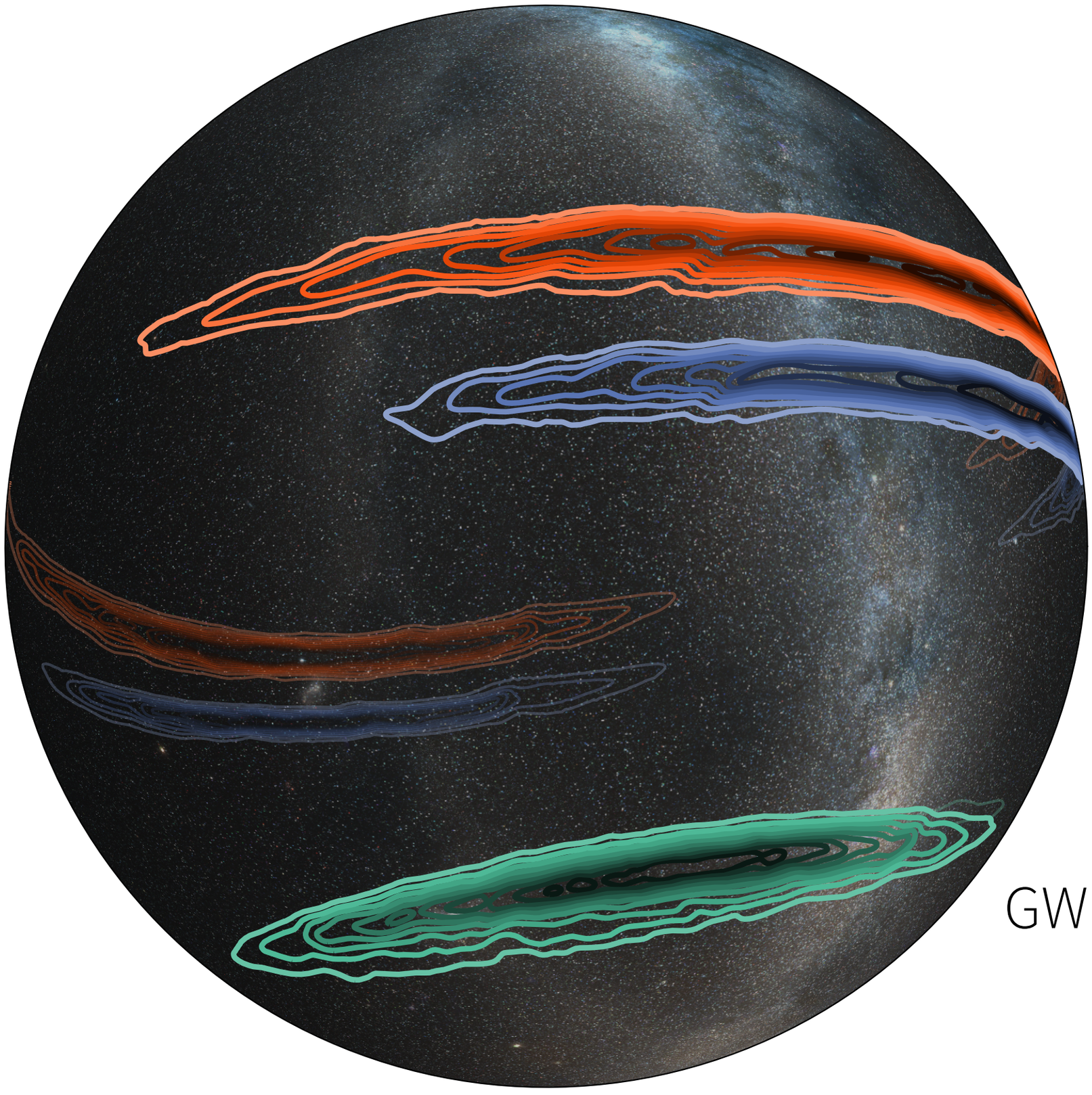
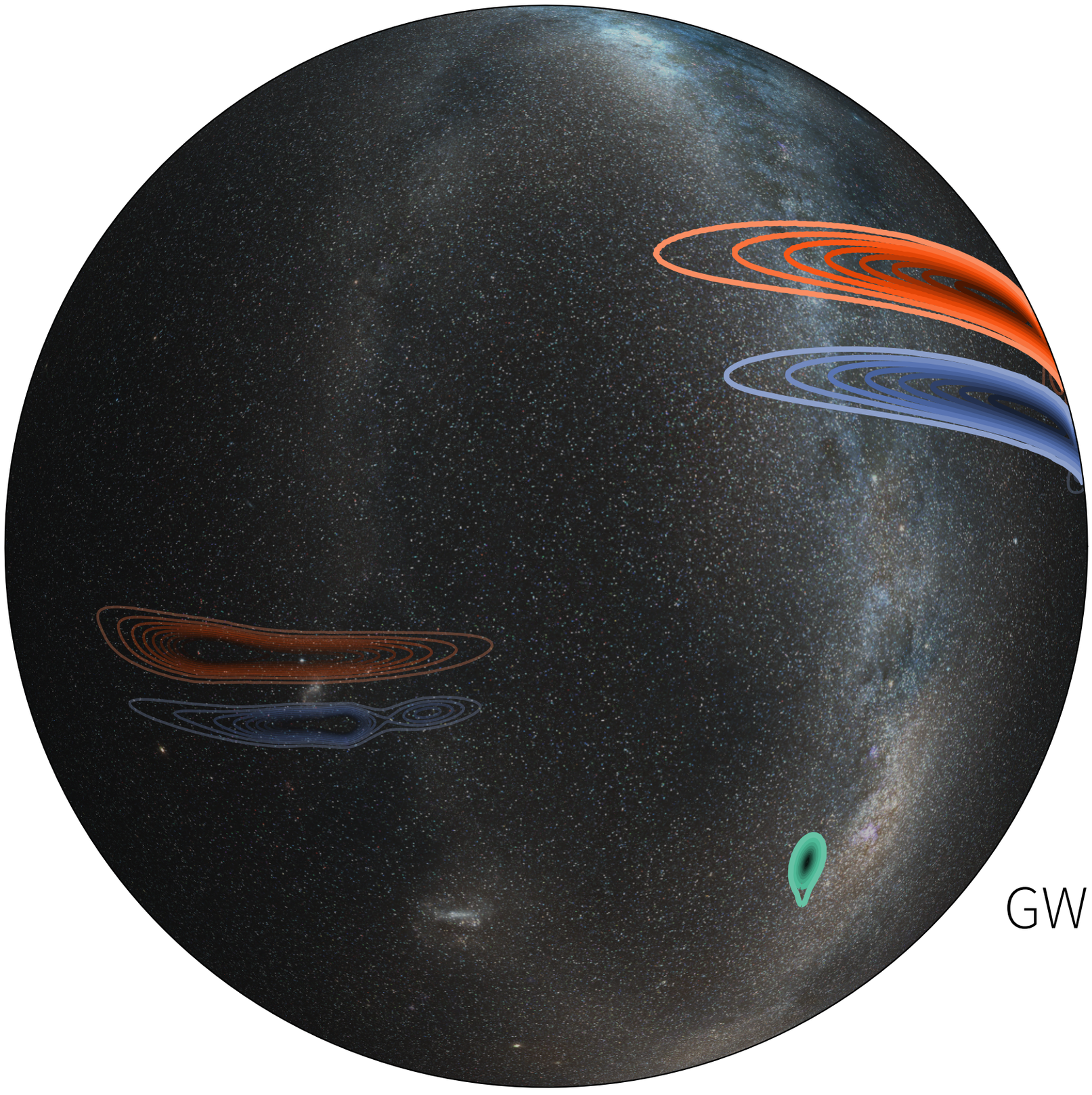


image credit: LIGO/Leo Singer (Milky Way image: Axel Mellinger)



LVT151012 **+VIRGO**

GW151226 **+VIRGO**

GW150914 **+VIRGO**

image credit: LIGO/Leo Singer (Milky Way image: Axel Mellinger)

Case study: varying preliminary sensitivity of Advanced Virgo

- TL;DR: If Virgo's range is 25% of LIGO's, then Virgo shrinks our localizations to ~60% of their HL-only size.

- Assume LIGO (H, L) BNS range of 81 Mpc:
  "mid, low” curve from Obs. Scenarios document, also approximately what was achieved in O1

- Assume baseline Virgo (V) BNS range of 21 Mpc:
  "early, low” curve from Obs. Scenarios document

- Vary Virgo range from 0.1x to ~4x the baseline, for ranges of ~2 to ~84 Mpc

- Uniform and isotropic sample of BNS events and selected those that would be detectable assuming a single-detector threshold SNR of 4, a minimum of 2 detectors above threshold, and a network SNR threshold of 12.

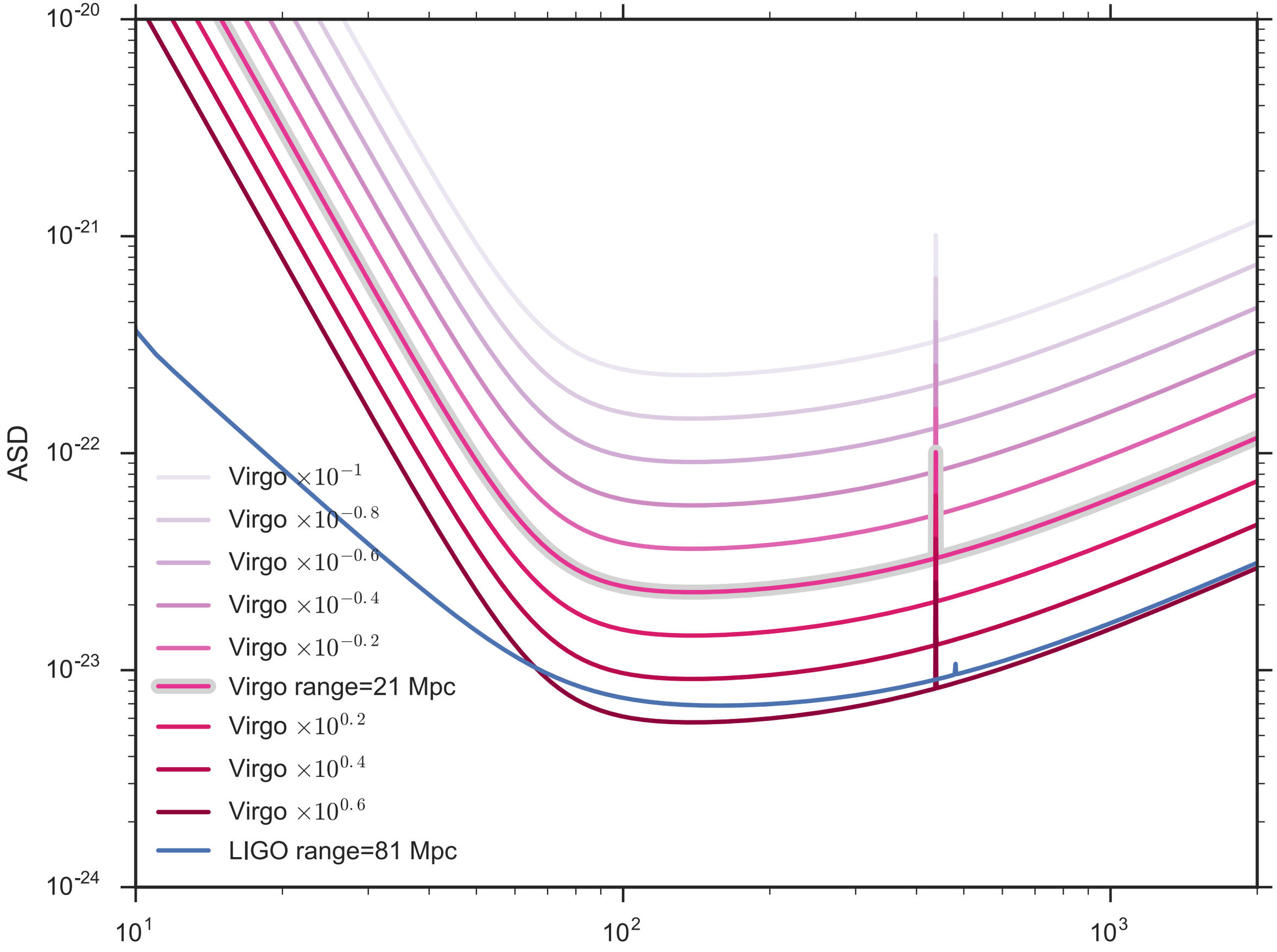


image credit: Leo Singer

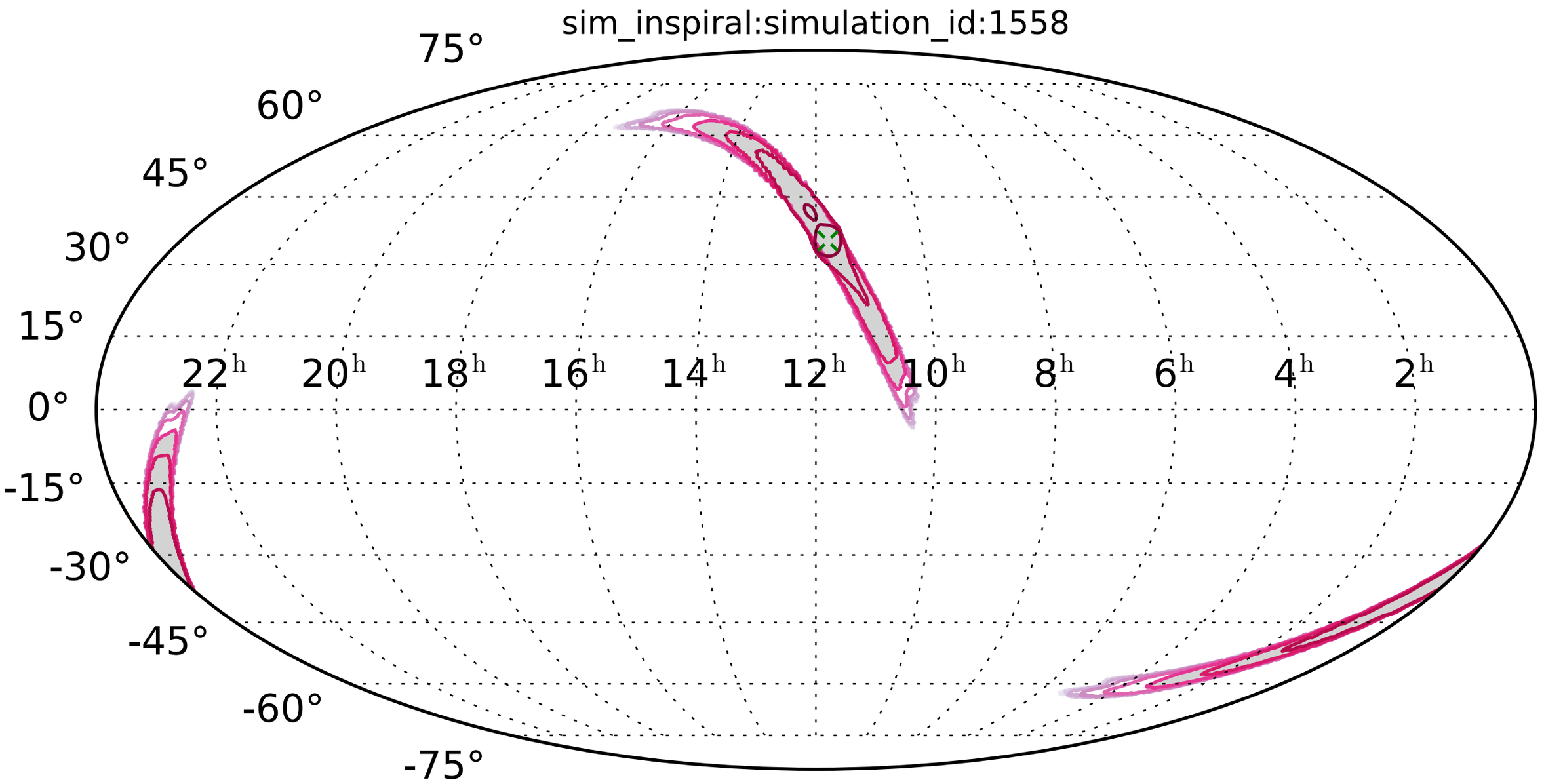


image credit: Leo Singer

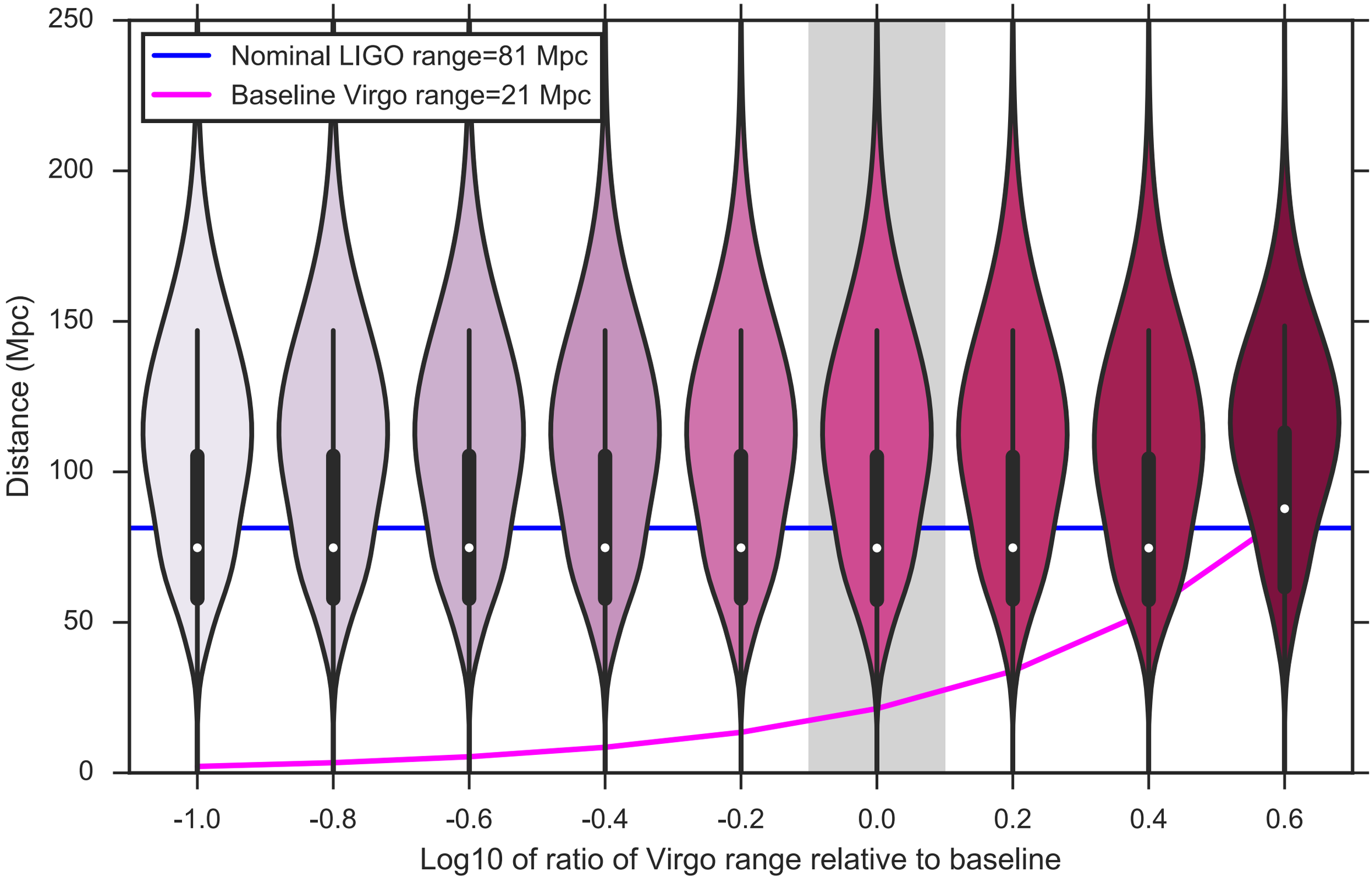


image credit: Leo Singer

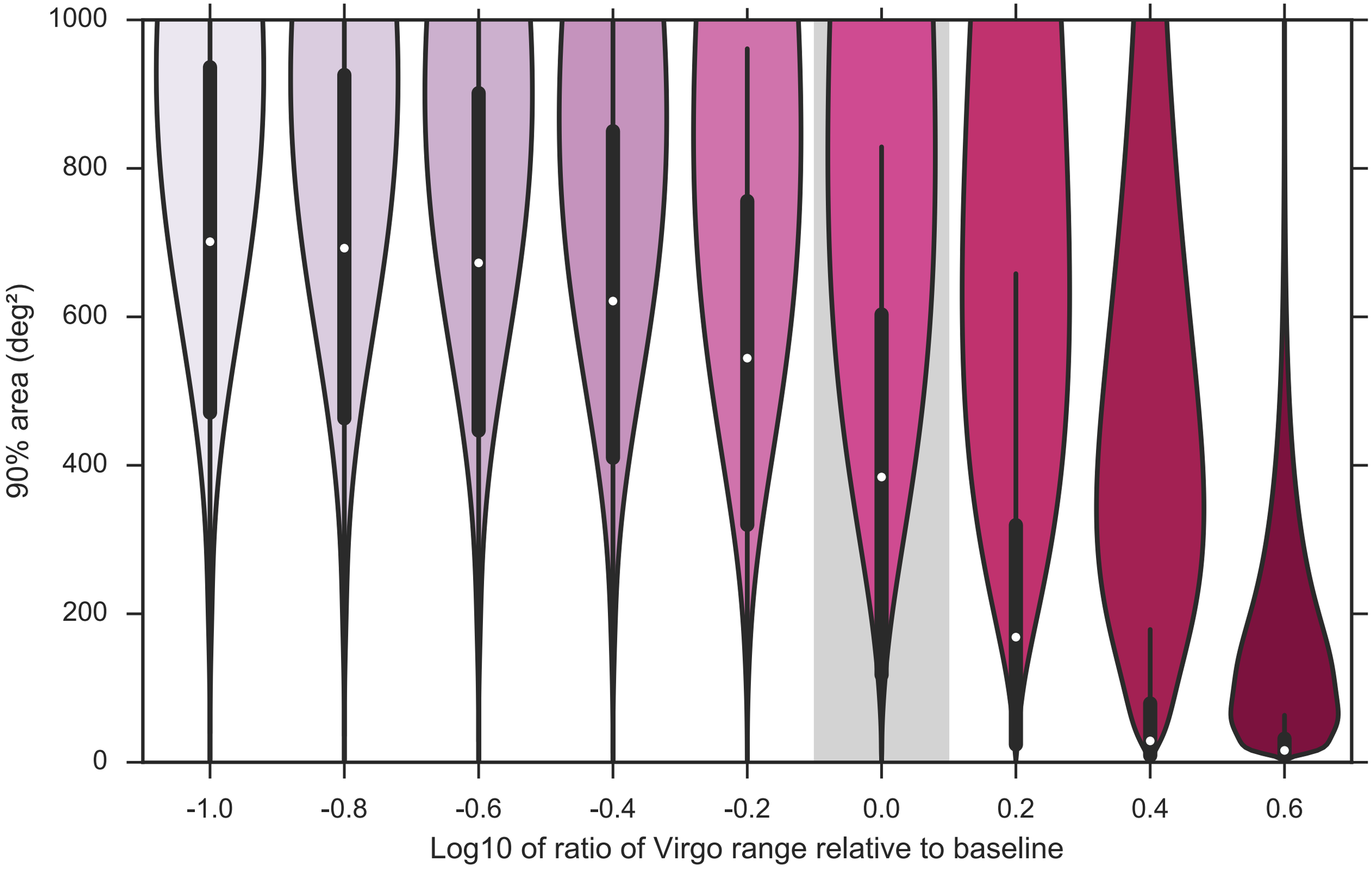


image credit: Leo Singer

Conclusions

- O(10) BBH signals by O2, O(100) by O3. Detections or meaningful limits for BNS and NSBH binaries by O2/O3.

- The detection rate is set by the range of the second most sensitive detector.

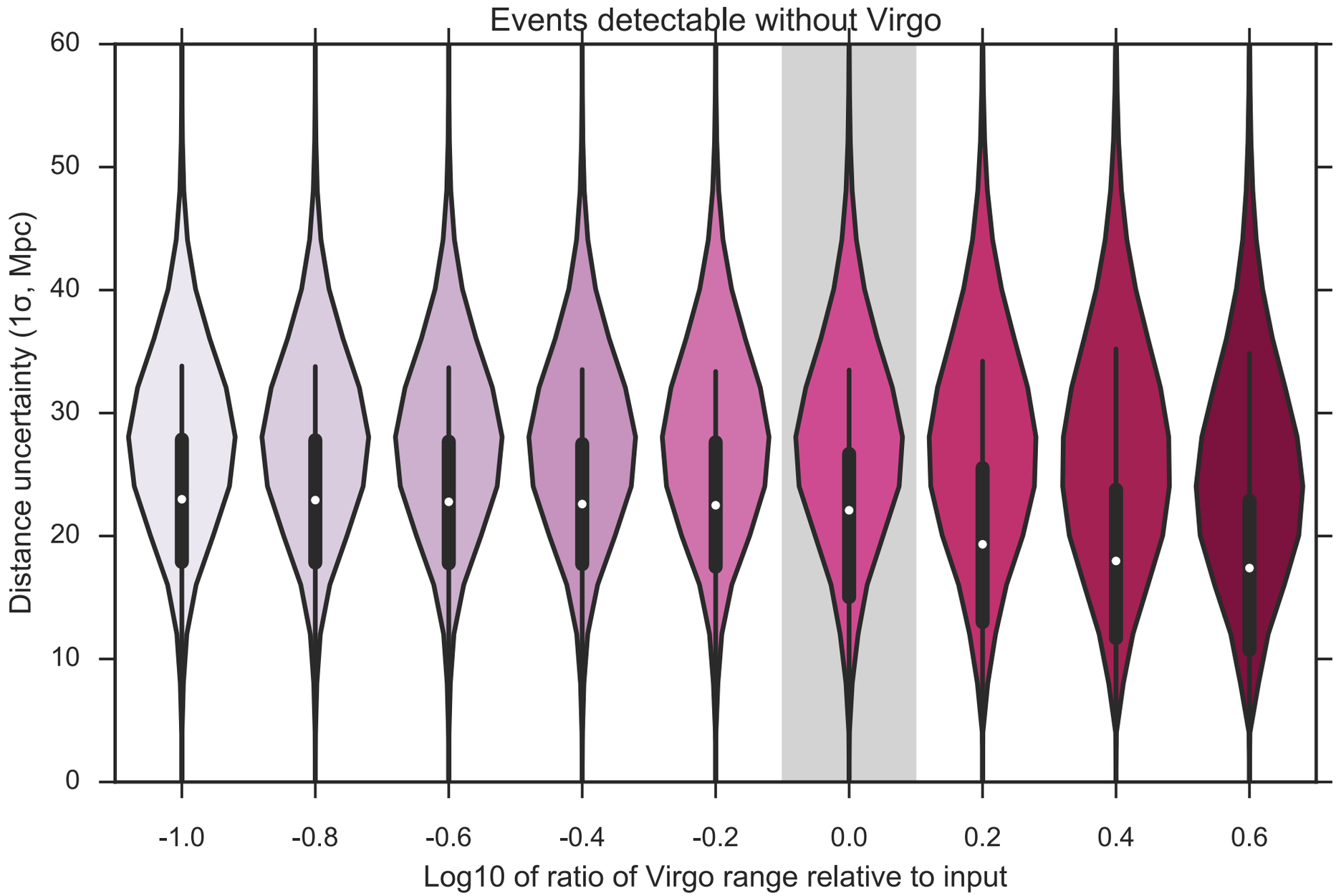
- Accurate sky localization is achieved by maximizing the range of the third most sensitive detector.

- **Therefore,** localization will begin improving once a third detector is online **at any sensitivity**.

- Point of reference: median 90% area improves by a factor of **60%** if Virgo is **1/4** as sensitive as LHO/LLO.

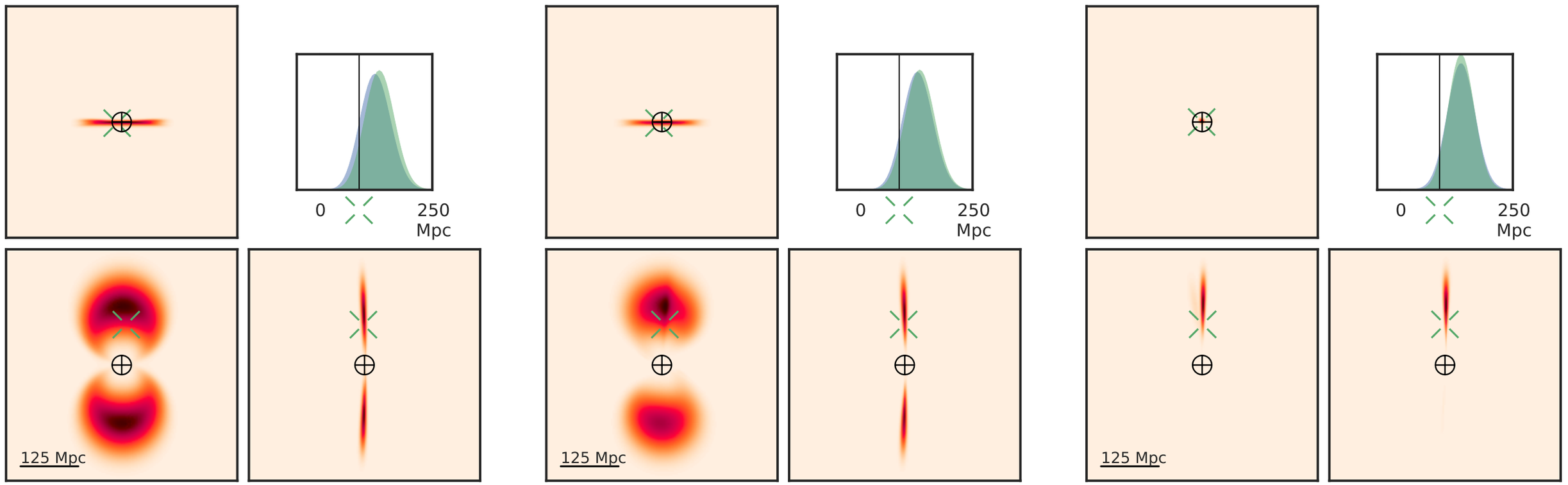
Extra Slides

Distance accuracy is not sensitive to Virgo range (see S. Vitale's presentation)



Distance accuracy improves by only a factor ~0.7 at equal sensitivity

Example 3D position reconstruction with HLV network



After “Going the Distance”, Singer+ 2016, arXiv:1603.07333