大型低温重力波望遠鏡に関する研究（Ⅸ）II

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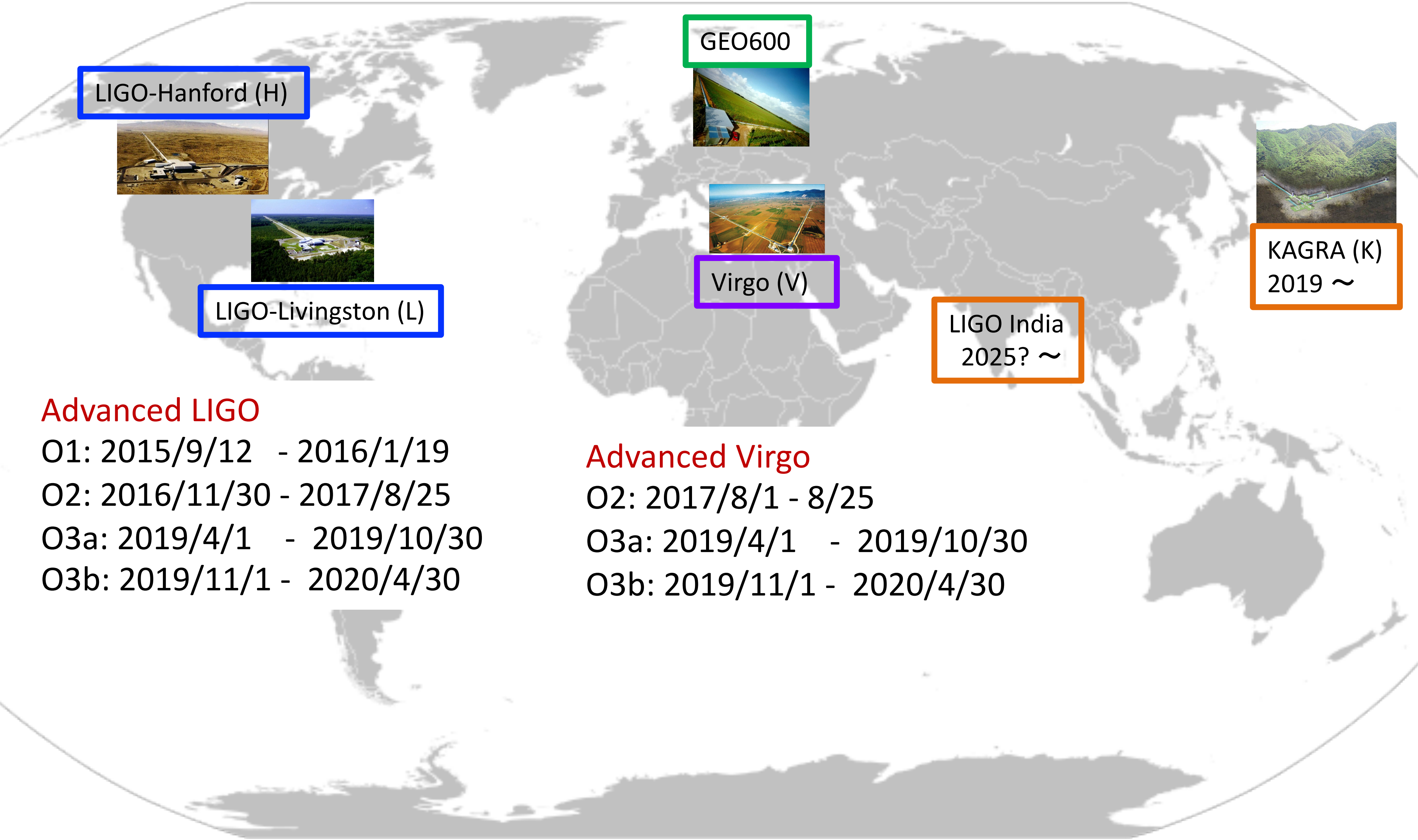
令和元年度東京大学宇宙線研共同利用研究成果発表会　令和元年12月13日

目次

- LIGO/Virgo O1, O2観測のまとめ
- LIGO/Virgo O3観測の状況
- KAGRAの状況，今後の計画と展望

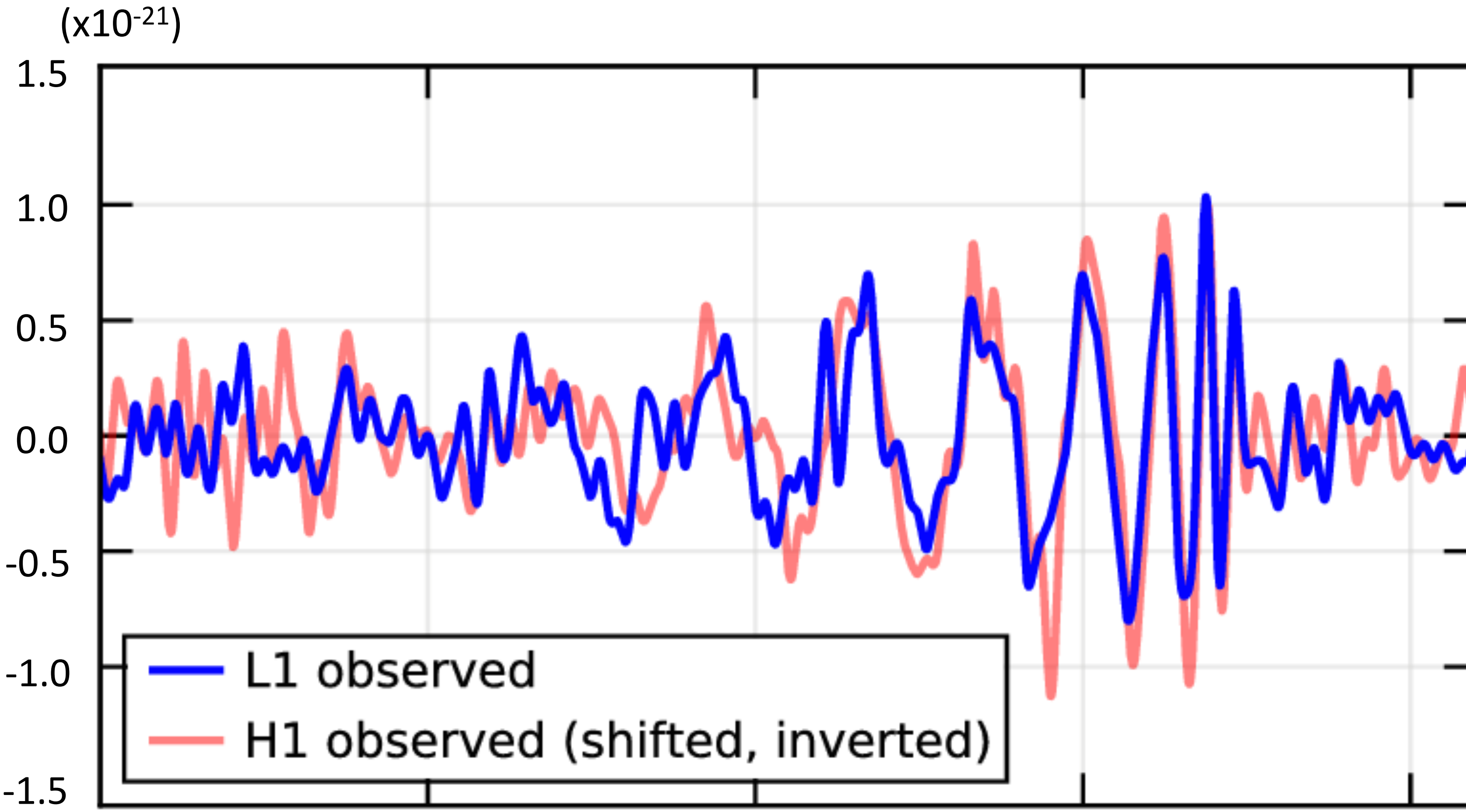
A global GW network



Advanced LIGO
O1: 2015/9/12 - 2016/1/19
O2: 2016/11/30 - 2017/8/25
O3a: 2019/4/1 - 2019/10/30
O3b: 2019/11/1 - 2020/4/30

Advanced Virgo
O2: 2017/8/1 - 8/25
O3a: 2019/4/1 - 2019/10/30
O3b: 2019/11/1 - 2020/4/30

First observation
– Binary black hole merger GW150914 –



LIGO-Virgo GW signals (by 2017)

Total 11 signals from Sept. 2015 to Jan. 2016（O1）and from Nov. 2016 to Aug. 2017（O2）

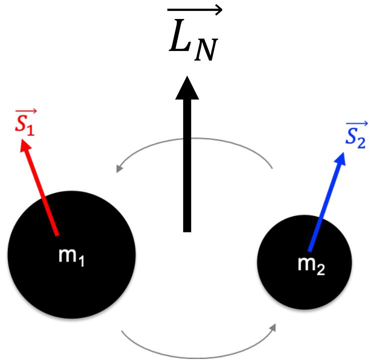
	ID	Type	mass1	mass2	χ_{eff}	mass after merger	distance	
	GW150914	BBH	35.6	30.6	-0.01	63.1	430	
previously called "LVT"	GW151012	BBH	23.3	13.6	0.04	35.7	1060	
	GW151226	BBH	13.7	7.7	0.18	20.5	440	
	GW170104	BBH	31.0	20.1	-0.04	49.1	960	
	GW170608	BBH	10.9	7.6	0.03	17.8	320	
new	GW170729	BBH	heaviest BH 50.6	34.3	0.36	80.3	2750	most massive most distant
new	GW170809	BBH	35.2	23.8	0.07	56.4	990	
	GW170814	BBH	30.7	25.3	0.07	53.5	580	
	GW170817	BNS	1.46	1.27	0.00	≦ 2.8	40	
new	GW170818	BBH	35.5	26.8	-0.09	59.8	1020	
new	GW170823	BBH	39.6	29.4	0.08	65.6	1850	
			Solar mass	Solar mass	non-dim	Solar mass	Mpc	

BBH: Binary Black Hole
BNS: Binary Neutron Star

Spins

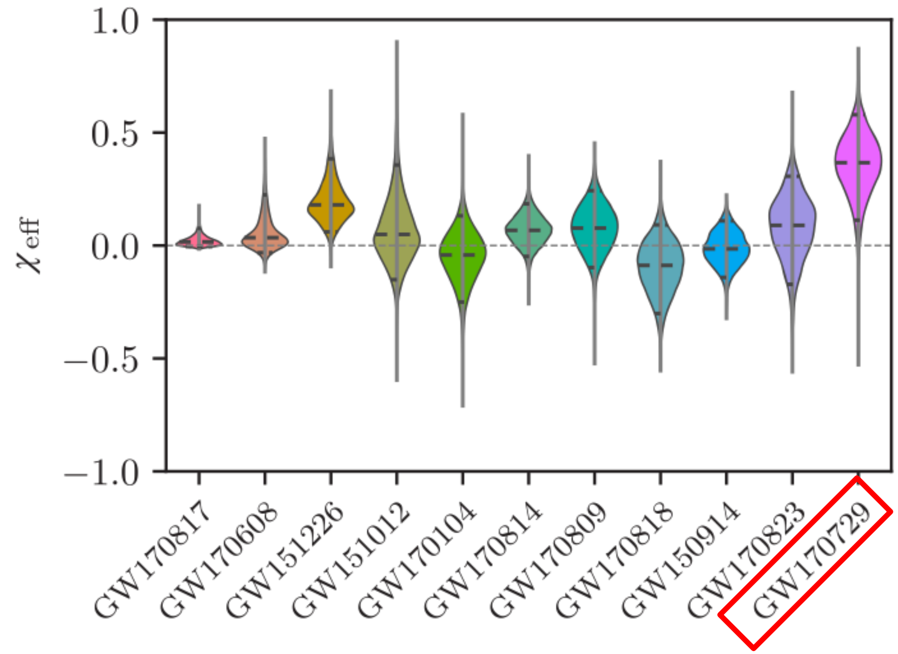
Phys. Rev. X 9, 031040 (2019)
arXiv:1811.12907

Unit normal to orbital plane



$$\chi_{\mathrm{eff}} = \frac{(\overrightarrow{S}_1/m_1 + \overrightarrow{S}_2/m_2)\cdot\overrightarrow{L}_N}{M_{\mathrm{tot}}}$$

Posterior distribution function



- One of key signatures to distinguish black hole populations
- Consistent with zero for most cases
- GW170729 shows positive effective spin

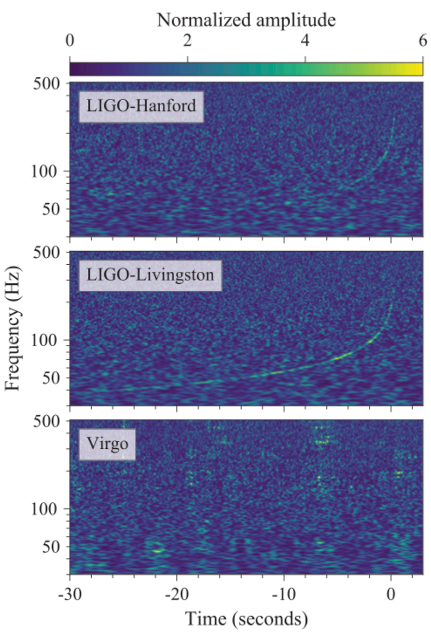
GW170817 and EM counterparts

Virgo joined observation => 3 detectors' network

GW170817

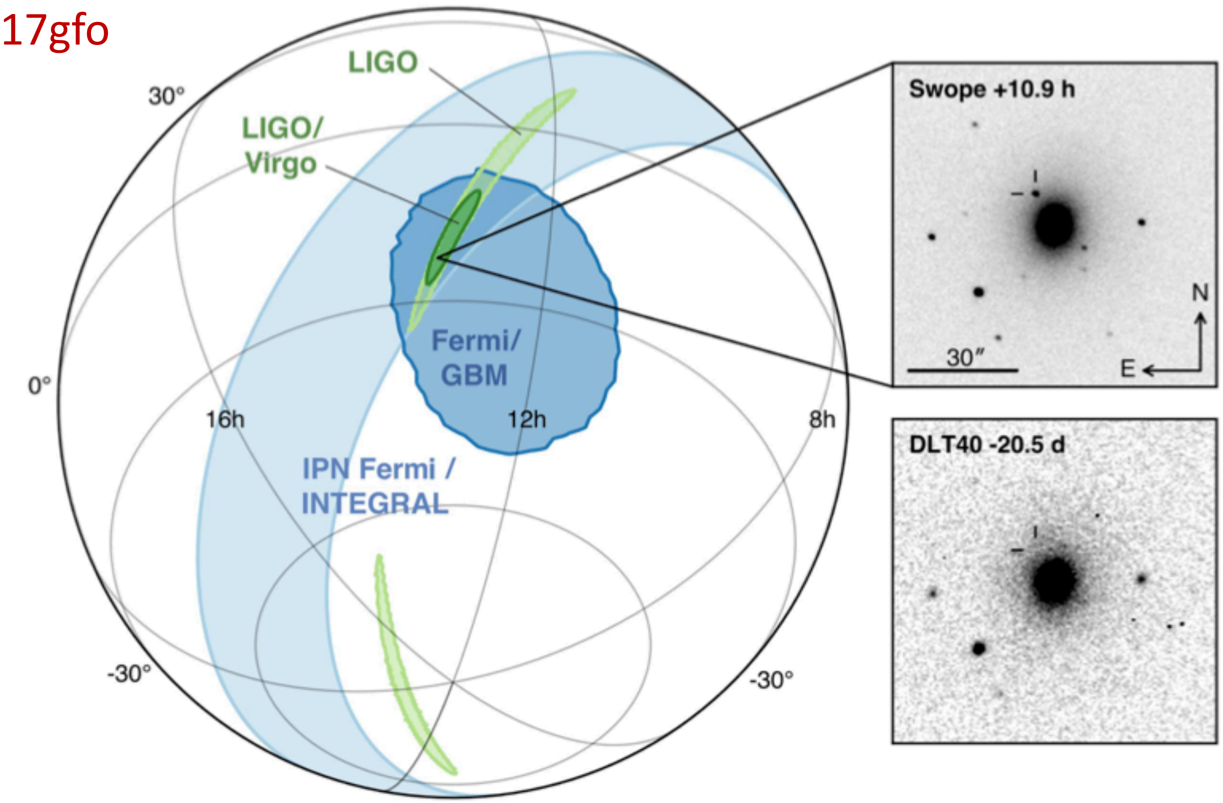
GRB170817A

Optical : SSS17a / AT2017gfo



8:L12 (59pp), 2017 October 20

Abbott et



NGC4993

Figure 1. Localization of the gravitational-wave, gamma-ray, and optical signals. The left panel shows an orthographic projection of the 90% credible regions fr
LIGO (190 deg^2; light green), the initial LIGO-Virgo localization (31 deg^2; dark green), IPN triangulation from the time delay between *Fermi* and *INTEGRAL* (li
blue), and *Fermi*-GBM (dark blue). The inset shows the location of the apparent host galaxy NGC 4993 in the Swope optical discovery image at 10.9 hr after
merger (top right) and the DLT40 pre-discovery image from 20.5 days prior to merger (bottom right). The reticle marks the position of the transient in both imag

GW170817 results

- Property of neutron star matter
  - Constraint to tidal deformability

- EM counterparts observations
  - Coincidence with short GRB

  - Observation of Kilonova/Macronova
    - ✓ Signature of r-process nucreosynthesis

  - New independent constraint to Hubble parameter
    - ✓ Distance determination with gravitational waves

  - Constraint to speed of gravity

$$-3 \times 10^{-15} \leq \frac{\Delta v}{v_{\mathrm{EM}}} \leq 7 \times 10^{-16} \qquad \Delta v = v_{\mathrm{GW}} - v_{\mathrm{EM}}$$

LIGO-Virgo O3

O3a: April 1, 2019 – October 31, 2019
O3b: November 1, 2019 – April 30, 2020

LIGO-Virgo O3a candidates

2019/4/1 - 2019/9/30

Number of alert sents to GCN circular: 34 (7 retractions are not included)

ID	Type	Distance[Mpc]	Localization [sq. deg]
S190408an	BBH	1473	387 (HLV)
S190412m	BBH	812	156 (HLV)
S190421ar	BBH	1628	1444 (HL)
S190425z	BNS	156	7461 (LV)
S190426c	BNS? / noise?	377	1131 (HLV)
S190503bf	BBH	421	448 (HLV)
S190510g	BNS? / noise?	227	1166 (HLV)
S190512at	BBH	1388	252 (HLV)
S190513bm	BBH	1987	691 (HLV)
S190517h	BBH	2950	939 (HLV)
S190519bj	BBH	3154	967 (HLV)
S190521g	BBH	3931	765 (HLV)
S190521r	BBH	1136	488 (HL)

LIGO-Virgo O3a candidates

2019/4/1 - 2019/9/30, 34 (7 retractions are not included)

ID	Type	Distance[Mpc]	Localization [sq. deg]
S190602aq	BBH	797	1172 (HLV)
S190630ag	BBH	926	1483 (LV)
S190701ah	BBH	1849	49 (HLV)
S190706ai	BBH	5263	826 (HLV)
S190707q	BBH	781	921 (HL)
S190718y	BNS? / noise?	227	7246 (HLV)
S190720a	BBH	869	443 (HL)
S190727h	BBH	2839	151 (HLV)
S190728q	MassGap/BBH/NSBH	874	104 (HLV)
S190814bv	NSBH	267	23 (HLV)
S190816u	--------	-------	5855 (LV)
S190828j	BBH	1946	228 (HLV)
S190828l	BBH	1528	359 (HLV)
S190901ap	BNS	241	14753 (LV)

LIGO-Virgo O3a candidates

2019/4/1 - 2019/9/30, 34 (7 retractions are not included)

ID	Type	Distance[Mpc]	Localization [sq. deg]
S190910d	NSBH	632	2482 (HL)
S190910h	BNS? / noise?	230	24264 (L)
S190915ak	BBH	1584	318 (HLV)
S190923y	NSBH? / noise?	438	2107 (HL)
S190924h	MassGap	548	303 (HLV)
S190930s	MassGap	752	1998 (HL)
S190930t	NSBH? / noise?	108	24220 (L)

LIGO-Virgo O3b candidates

2019/11/1 - 2020/4/30: 6 (as of today)

ID	Type	Distance[Mpc]	Localization [sq. deg]
S191105e	BBH	1180	1297(LHV)
S191109d	BBH	1810	1487(LH)
S191129u	BBH	742	1011(LH)
S191204r	BBH	678	103(LHV)
S191205ah	NSBH	385	6378(LHV)
S191213g	BNS?	195	1393(LHV)

Today!

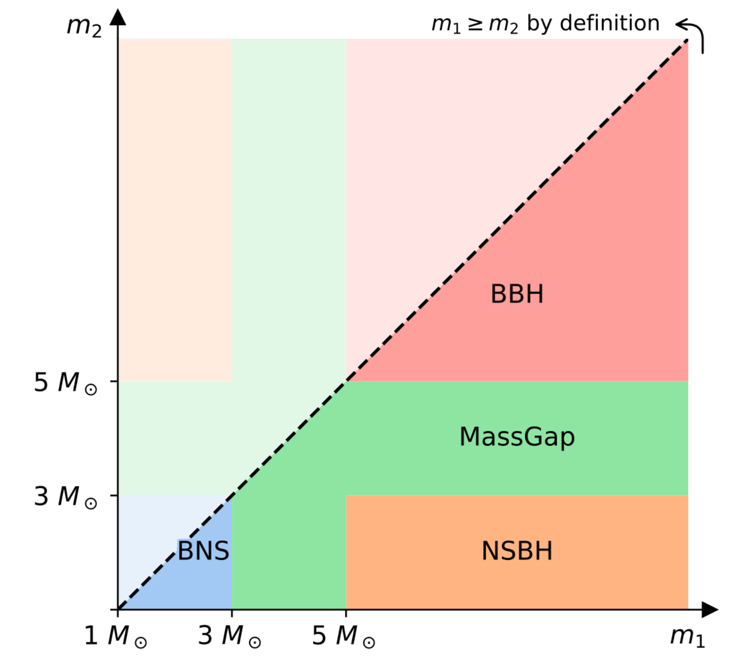
LIGO-Virgo O3 candidates

2019/4/1 - 2019/4/30,   Total 40 (as of today)

BBH	24
BNS	7
NSBH	5
MassGap	3

MassGap: Either or both masses are in 3-5Msun

Details of mass parameters etc. are not disclosed yet



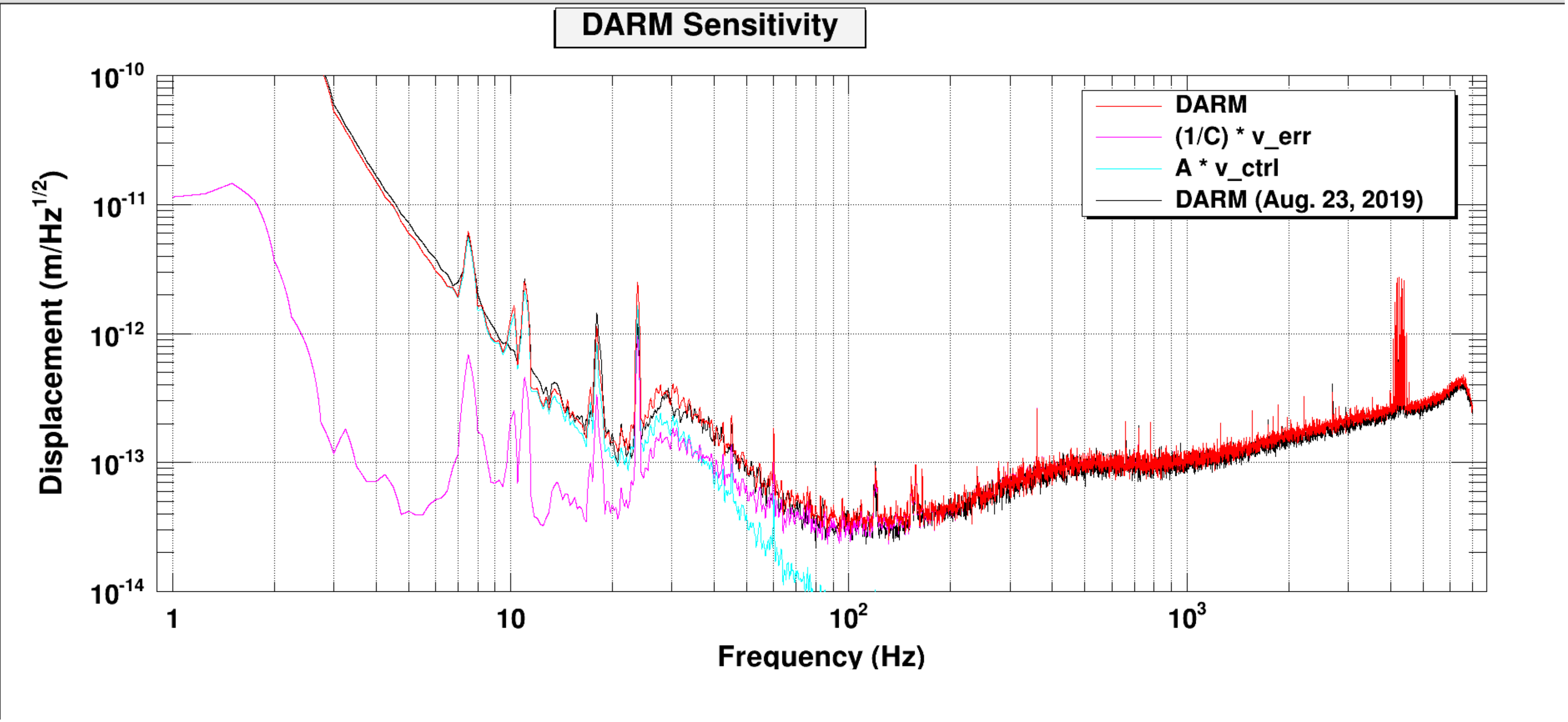
EM counterparts were not discovered

KAGRA

～15 countries, more than 300 collaborators

First light of KAGRA (First FPMI lock)

August 23, 2019



http://klog.icrr.u-tokyo.ac.jp/osl/index.php?c=1

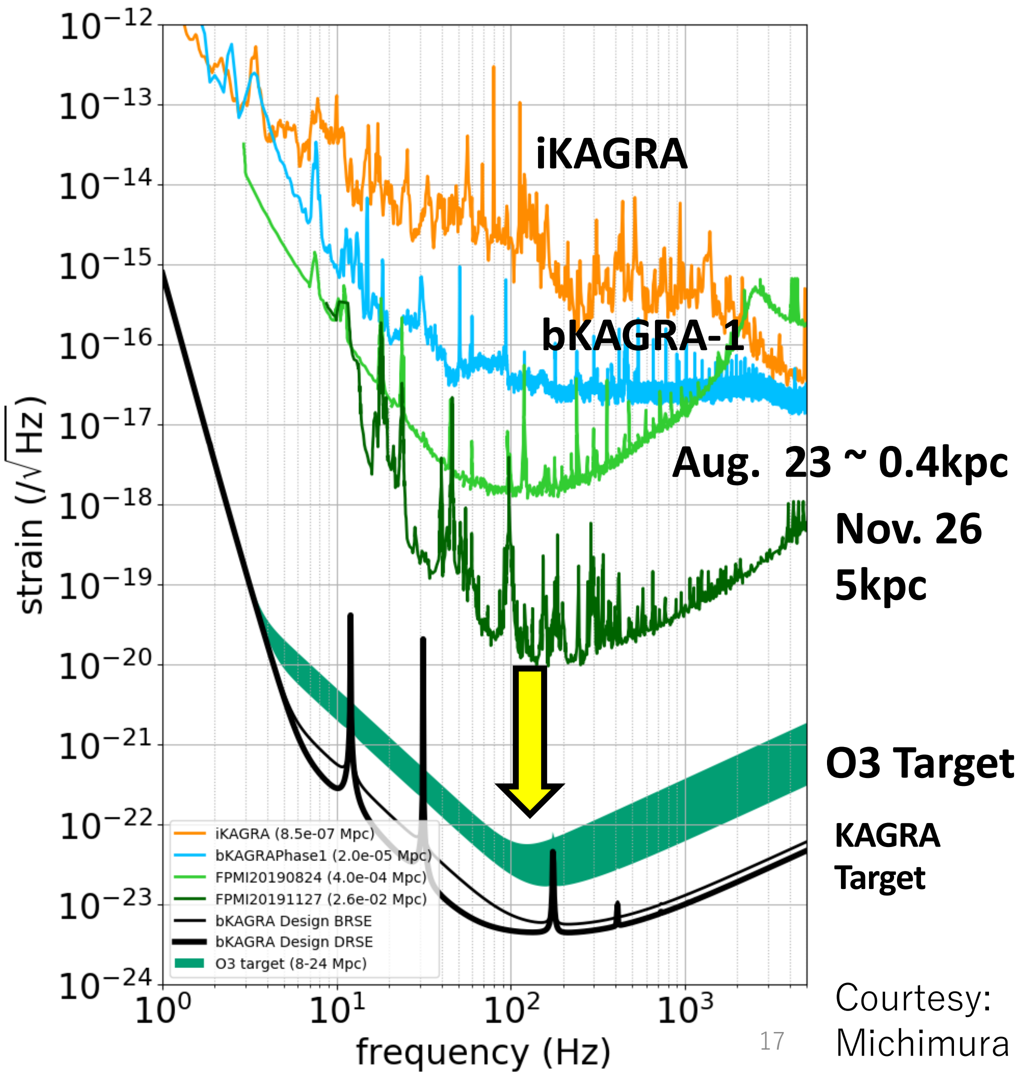
Timeline

iKAGRA (2016/4-5):
Michelson interferometer, room temp.

bKAGRA-1(2018/4-5) :
Michelson interferometer using one cryogenic ETM.

bKAGRA-2(Current-O3):
Fabry-Perot Michelson Interferometer.
Cryogenic test masses.
(BNS Range) > 1Mpc
1 week Engineering Run from Dec. 17

KAGRA Target:
PRFPMI + RSE, ~ 150Mpc



Data Analysis Committee and working groups

	Chair	Vice-chairs
DAC	Hideyuki Tagoshi	
Compact Binary Coalescence (CBC)	Hideyuki Tagoshi	Hyung Won Lee Kipp Cannon Tjonnie Li
Burst	Kazuhiro Hayama	
Continous Waves	Yousuke Itoh	
Stochastic Background	Guo-Chin Liu	Sachiko Kuroyanagi
Computing and Software	Ken-ichi Oohara	Kazuki Sakai Hirotaka Takahashi
Detector Characterization	Keiko Kokeyama	
Calibration	Yuki Inoue	

Detector Characterization

KAGRA summary

FSCAN (internal) Omicron-IMC (internal) Omicron-PSL (internal) KAGRA PEM-MAP (open) KAGRA DetChar wiki KAGRA PEM wiki

GlitchPlot Catalog GlitchPlot introduction GlitchPlot wiki Past summary viewer Latest channel list

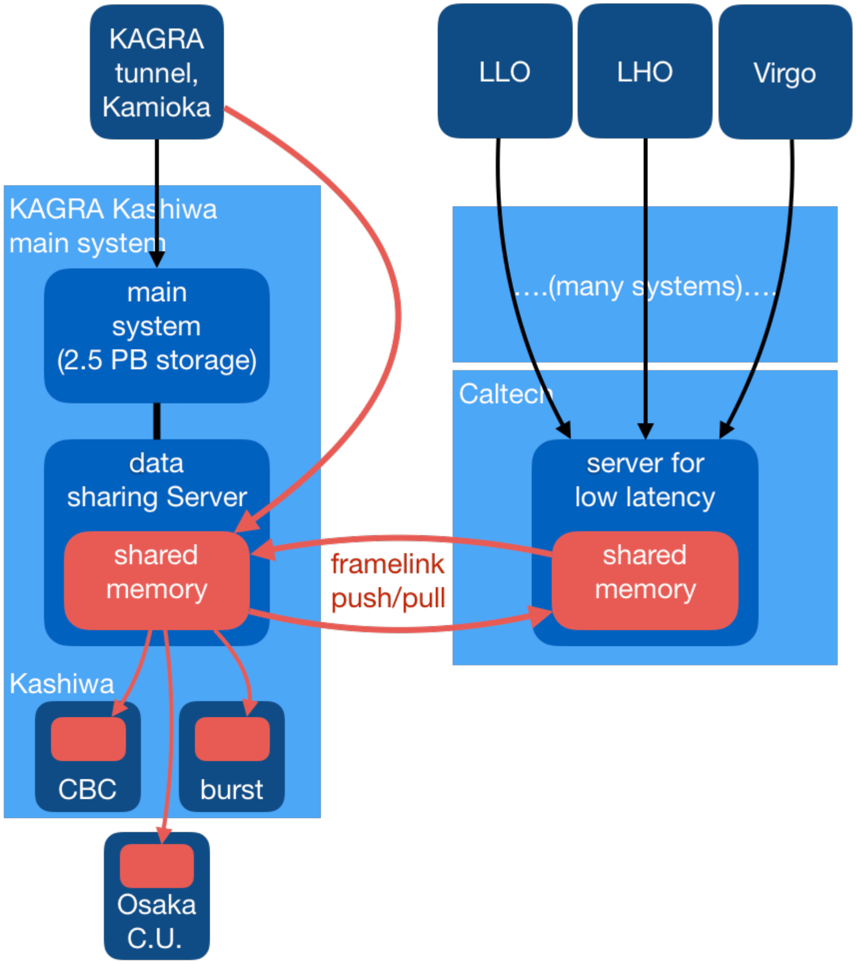
List of Date(all) List of Date(2018) List of Date(2019)

Latest channel GRD PSL IMC OMC VIS PEM CAL GlitchPlot JST : 20191212

>> 20191212 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191211 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191210 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191209 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191208 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191207 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191206 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191205 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191204 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191203 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191202 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191201 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191130 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191129 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191128 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191127 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191126 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191125 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191124 : General PSL IMC OMC VIS PEM CAL GlitchPlot
>> 20191123 : General PSL IMC OMC VIS PEM CAL GlitchPlot

Data transfer

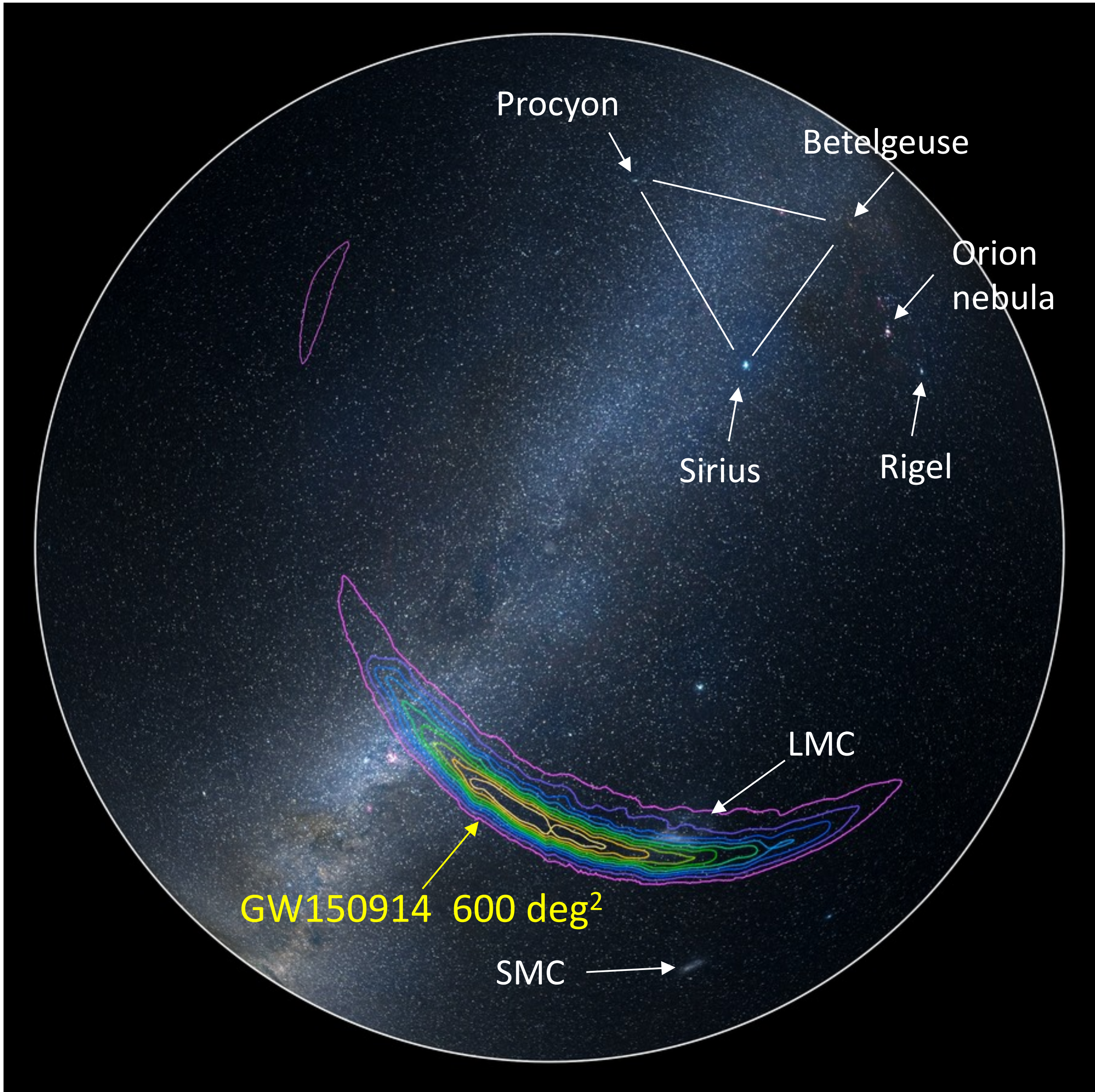
- DMG Group handles the data transfer issues.
  - Low latency h(t): 1 sec frame with a latency of a few sec.
  - Data exchange with LV
    - With “framelink”
    - Latency (4/20/2019): incl. h(t) reconstruction
      - Kamioka tunnel → Kashiwa: ~3 sec
      - **L → K: 6~14 sec., V → K: 10~16sec.,**
  - Bulk data
    - LDR implementation, but ··· will not be used.
    - We have to prepare LDR Alternative (simple method in O3, rucio in future.)



© N. Kanda & DMG (modified)

KAGRA's contribution: Source localization

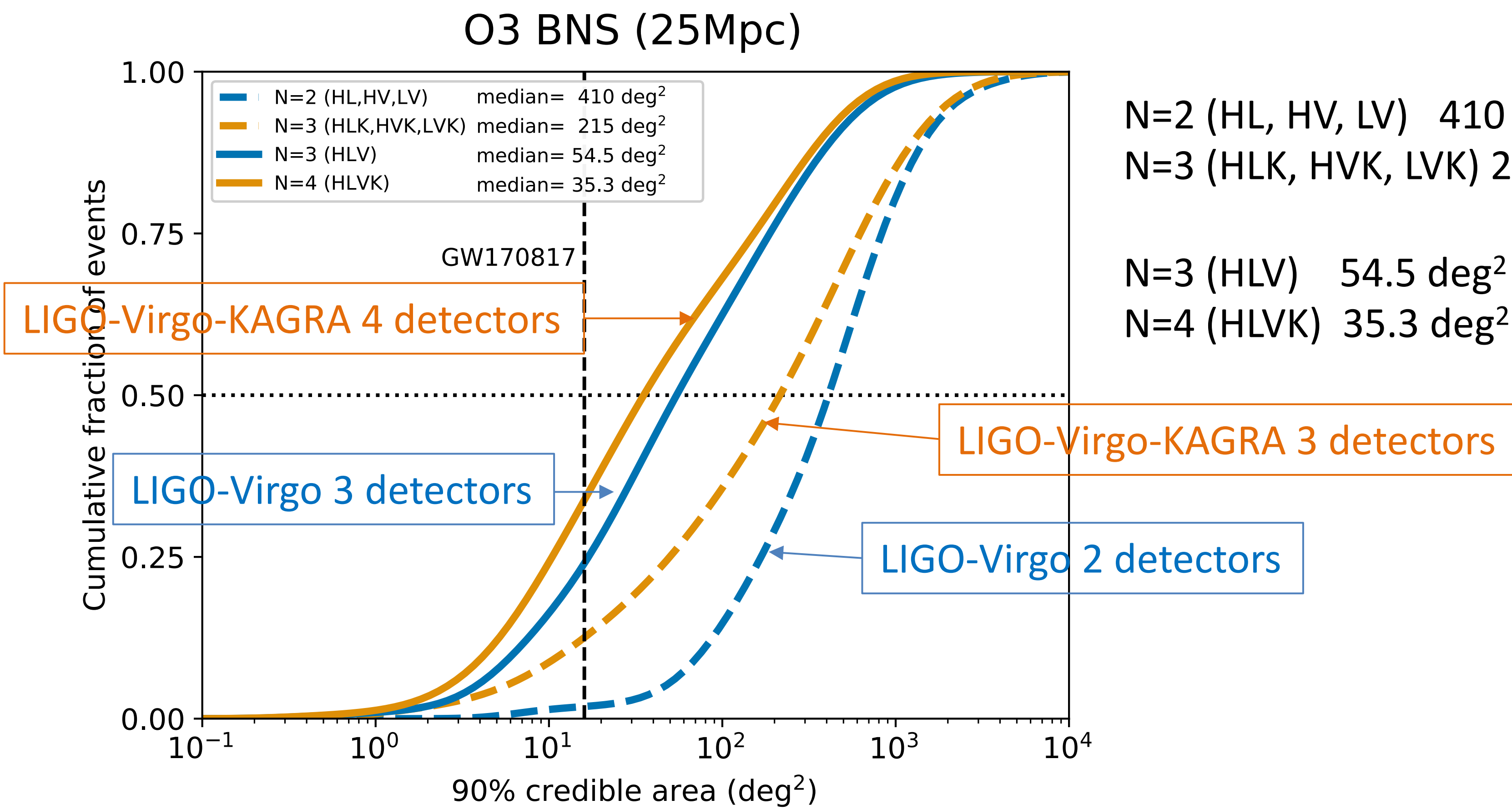
We need 3 or more detectors to determine source location accurately



https://www.ligo.caltech.edu/image/ligo20160211b

KAGRA's contribution: Source localization

Assumed sensitivity (BNS range)
LIGO 120Mpc, Virgo 60Mpc, KAGRA 25Mpc



N=2 (HL, HV, LV) 410 deg^2
N=3 (HLK, HVK, LVK) 215 deg^2

N=3 (HLV) 54.5 deg^2
N=4 (HLVK) 35.3 deg^2

KAGRA's contribution: Duty cycle

Duty cycle during O3

Hanford	Livingston	Virgo
69.7 %	72.9 %	76.4 %

Duty cycle of network observation during O3

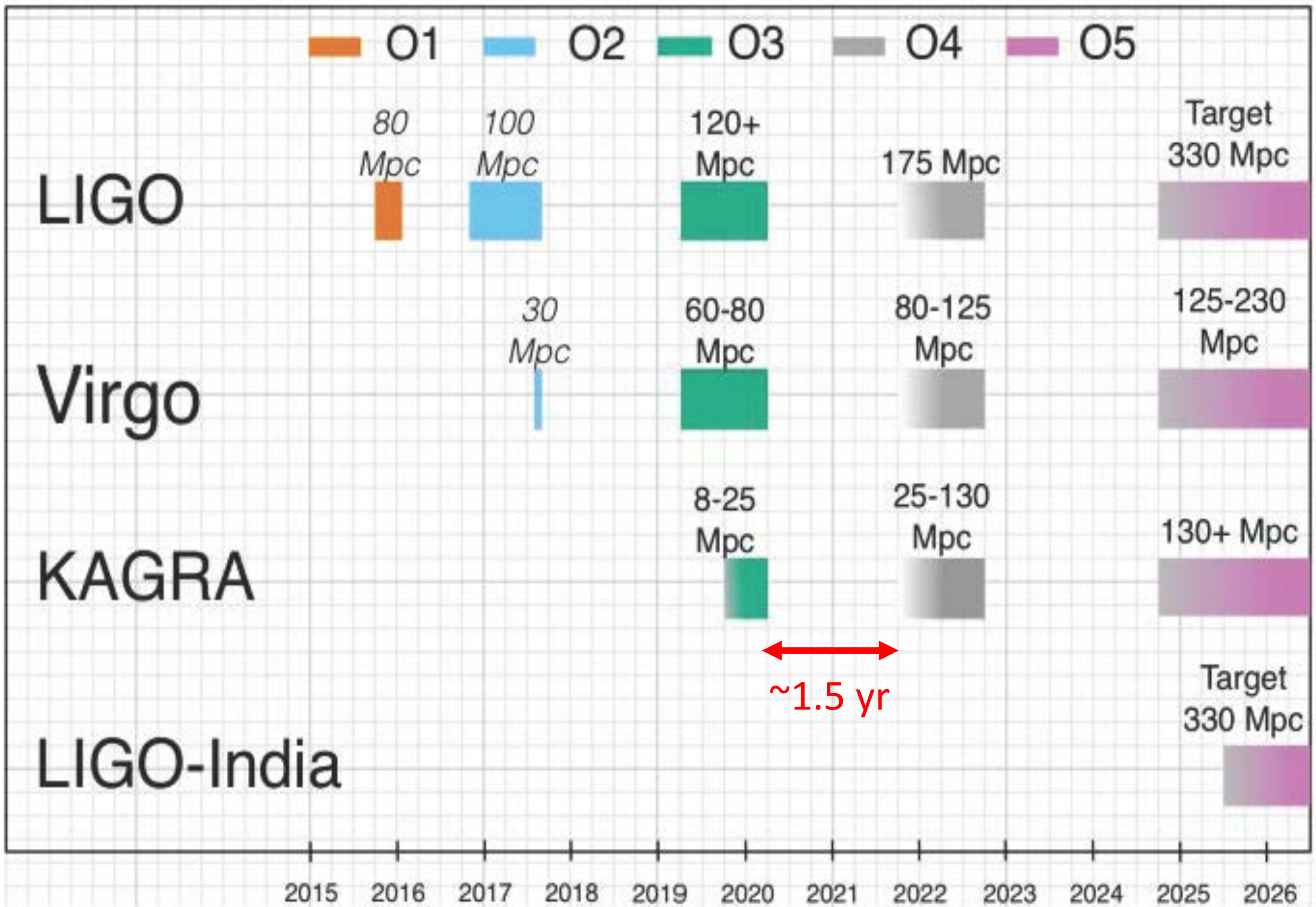
N=0	N=1	N=2	N=3
3.9 %	16.2 %	37.2 %	42.7 %

If KAGRA joins with duty cycle 70 %,

N=0	N=1	N=2	N=3	N=4
0.6 %	6.1 %	24.1 %	42.0 %	27.2

Duty cycle for operation with 3 or 4 detectors' network is about 70 %.

Observation plans in the future



What are expected in the near future

Many observations of binary coalescences

2 times sensitivities => observable distance is 2 times => event rate is 8 times !

BBH (～1 in one day)

- Distribution of BBH and hints for formation channels
- Tests of General Relativity

BNS (～1 in one week)
NSBH (～1 in 2 weeks)

- Constraint to equations of state of neutron stars
- EM follow-up observations
  - Clarify the relation to Short GRB
  - Kilonova and r-process nucleosynthesis
  - Constraint to Hubble parameter
  - ……

Summary

- LIGO-Virgo have observed 10 BBHs, 1 BNS during O1 and O2.
- In LIGO-Virgo O3, 40 candidates have been reported so far. But details are not announced yet.

- KAGRA is going to perform observation in FY2019.
- O4 is expected to start about 1.5 yr after the end of O3. KAGRA is planning to operate from the begining of O4 with much better sensitivity than O3.

- Various activities are ongoing to prepare observation.s
- A lot of results can be expected