LIMMA2019 @ The Dukes Retreat, Khandala, India

January 17, 2019

Status of KAGRA: Recent Progress towards O3 and Future Plans

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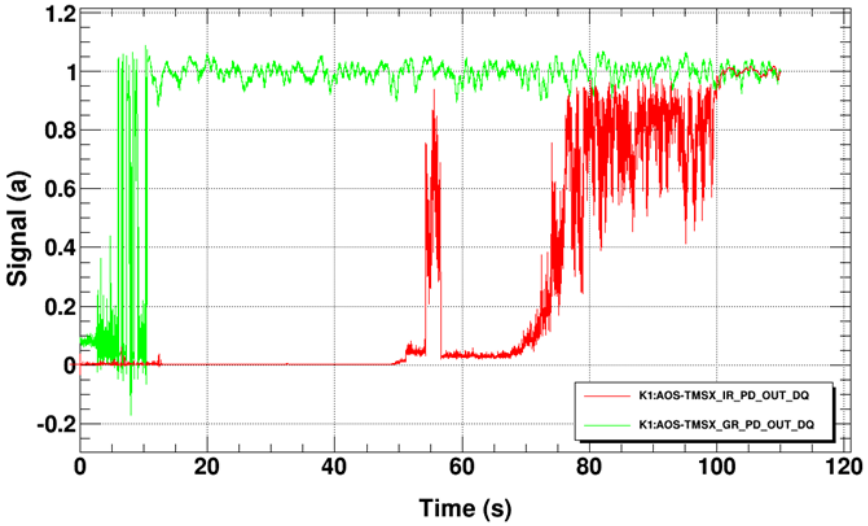
on behalf of the KAGRA Collaboration

Current Status of KAGRA

- First cryogenic test run with 3-km Michelson interferometer successfully done in May 2018
- Almost all the optics installed in vacuum
  - Cryogenic sapphire test masses
  - Signal recycling mirrors
  - Output faraday and output mode cleaner
- Successful completion of X-arm commissioning last week
- Y-arm and dual recycled Michelson commissioning starts this month
- Working hard to join O3 by the end of 2019



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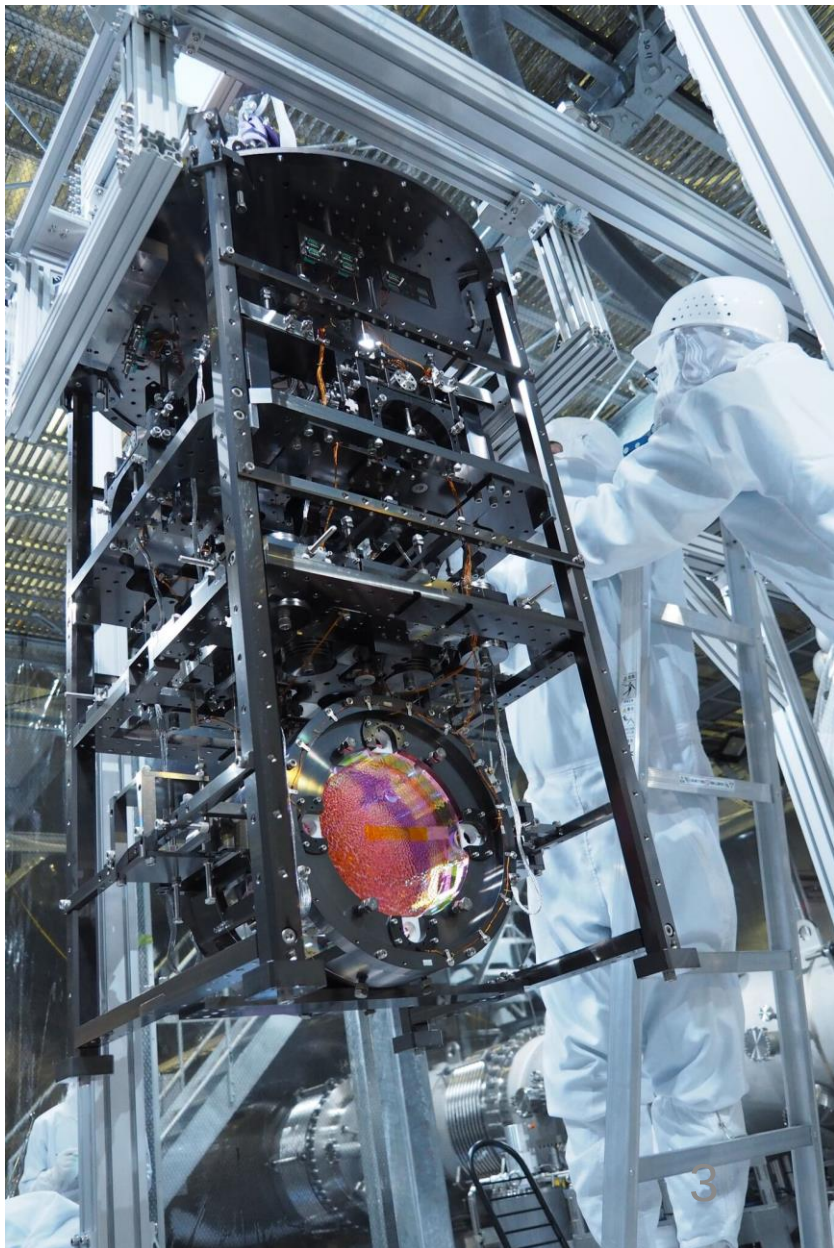
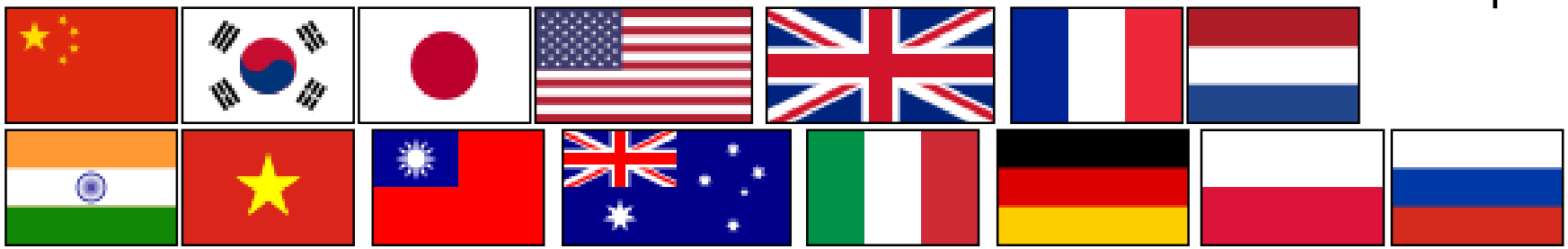


KAGRA Project

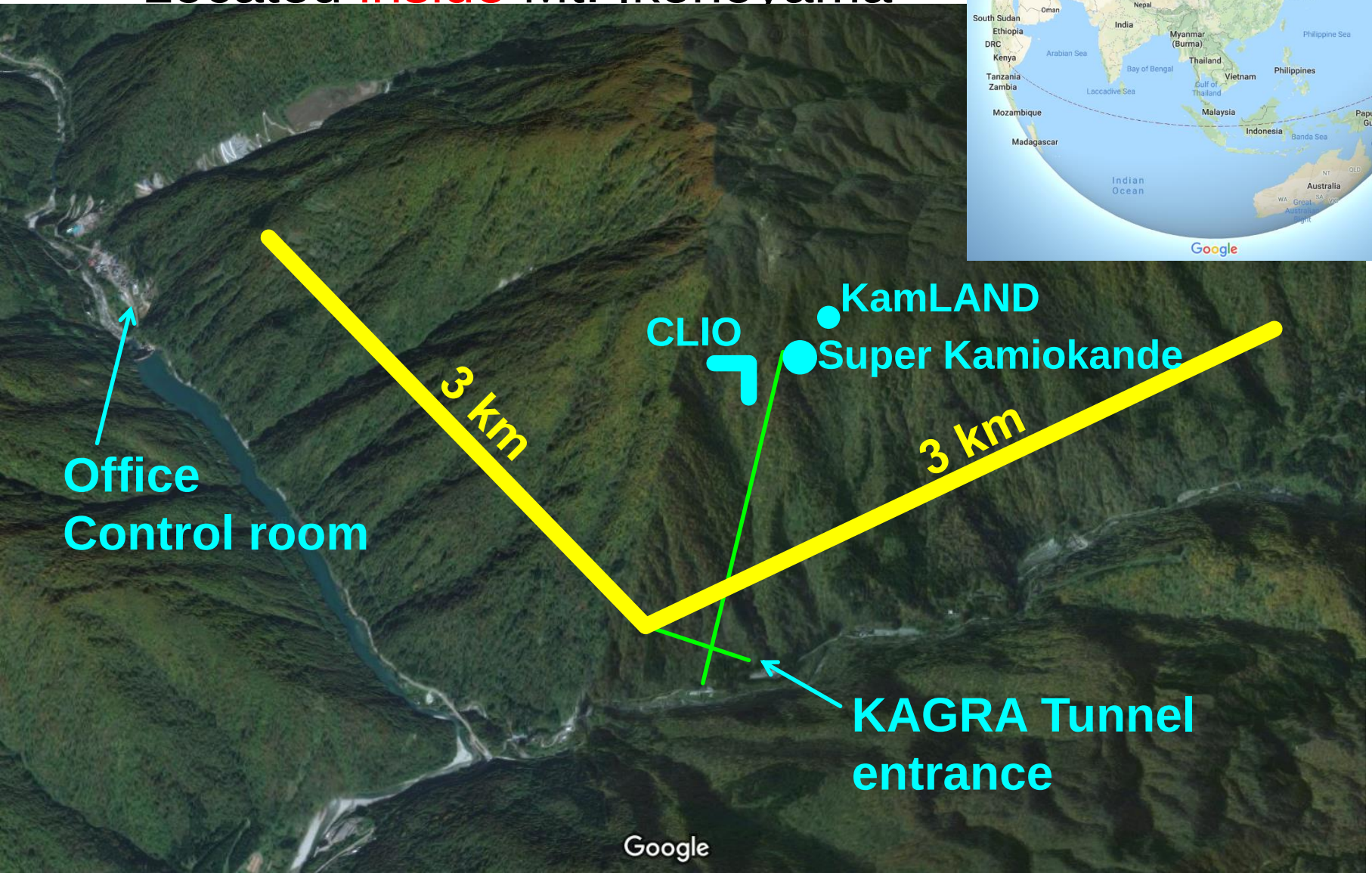
- Underground cryogenic interferometer in Japan
- Funded in 2010
- 97 institutes, 460 collaborators (162 authors)

as of Sept 2018



KAGRA Site

- Located inside Mt. Ikenoyama



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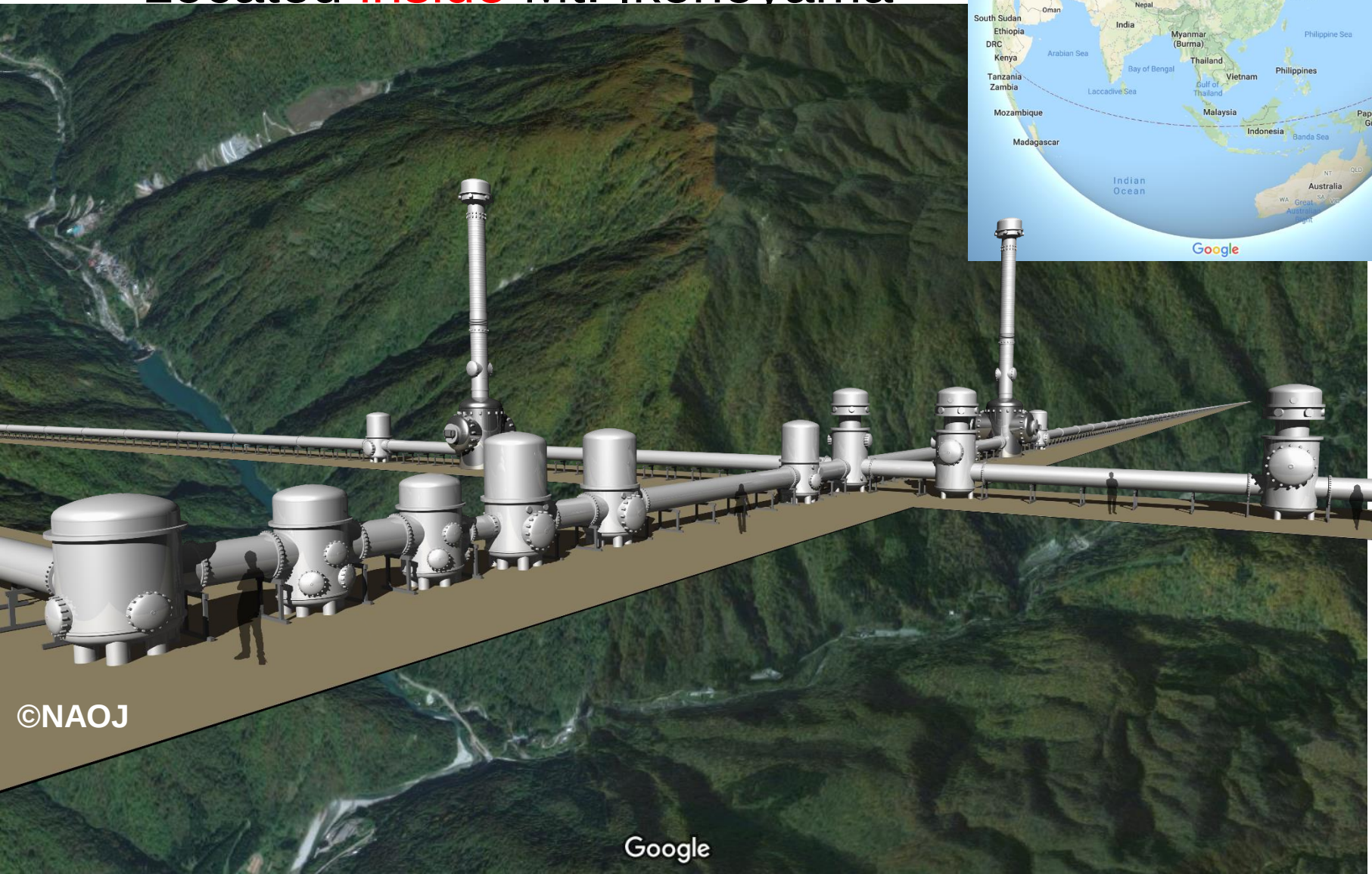
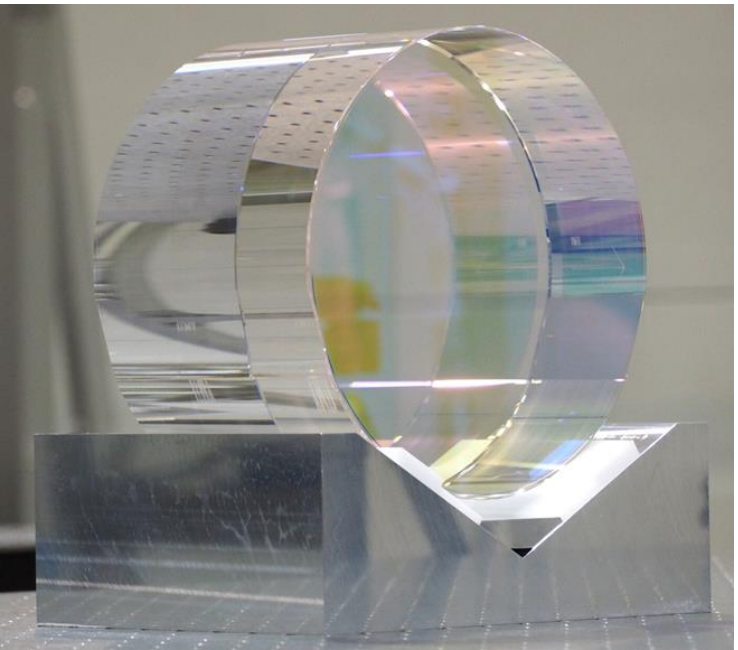


Interferometer Configuration

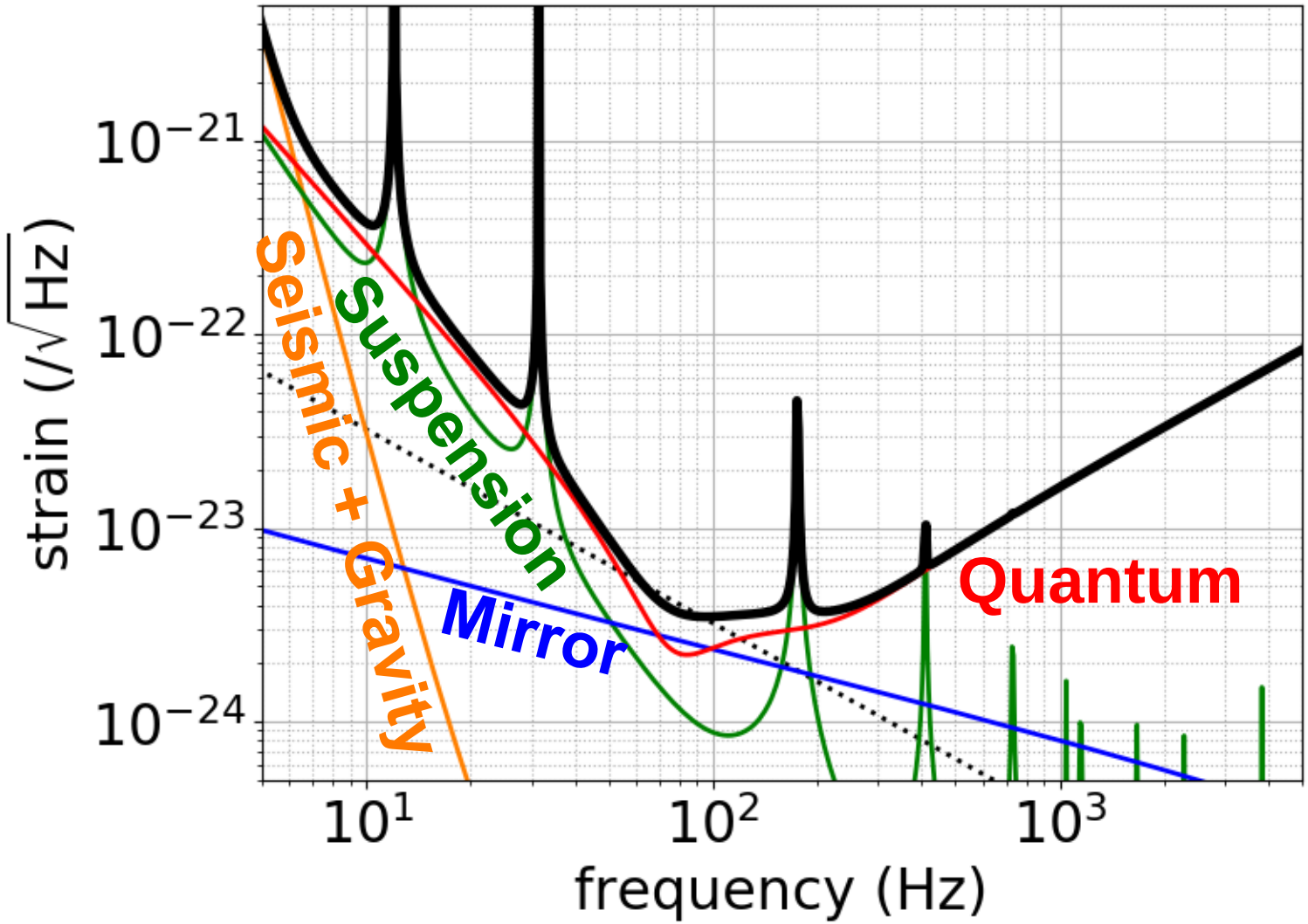
- RSE interferometer
- Cryogenic sapphire test masses



Φ22 cm x t 15 cm
22.8 kg

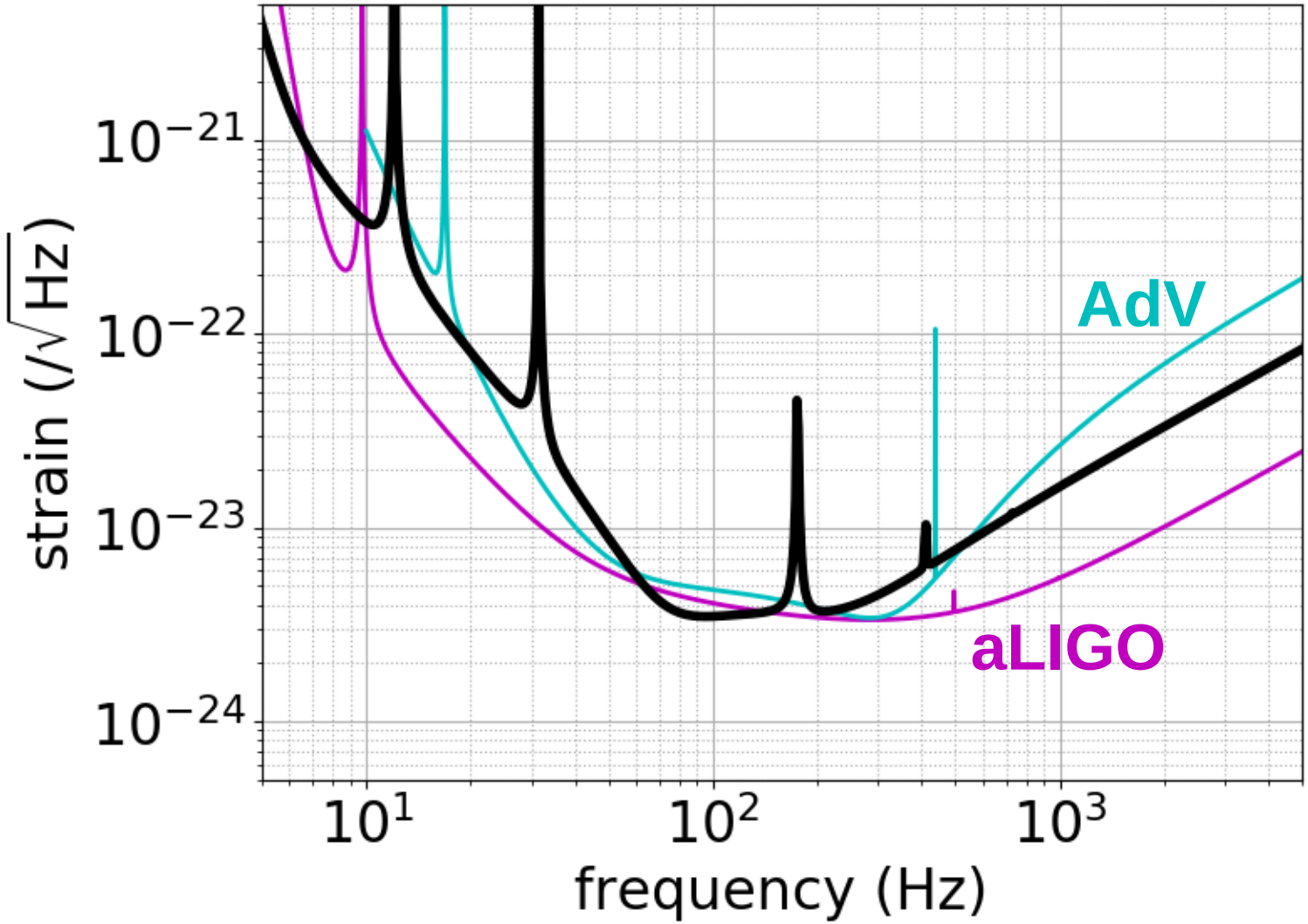
Design Sensitivity

- BNS range 153 Mpc (DRSE)



Comparison with aLIGO and AdV

- Comparable to aLIGO and AdV



KAGRA Timeline

Tunnel excavation done

Inauguration of initial-phase facility

First test run at room temp. (iKAGRA)

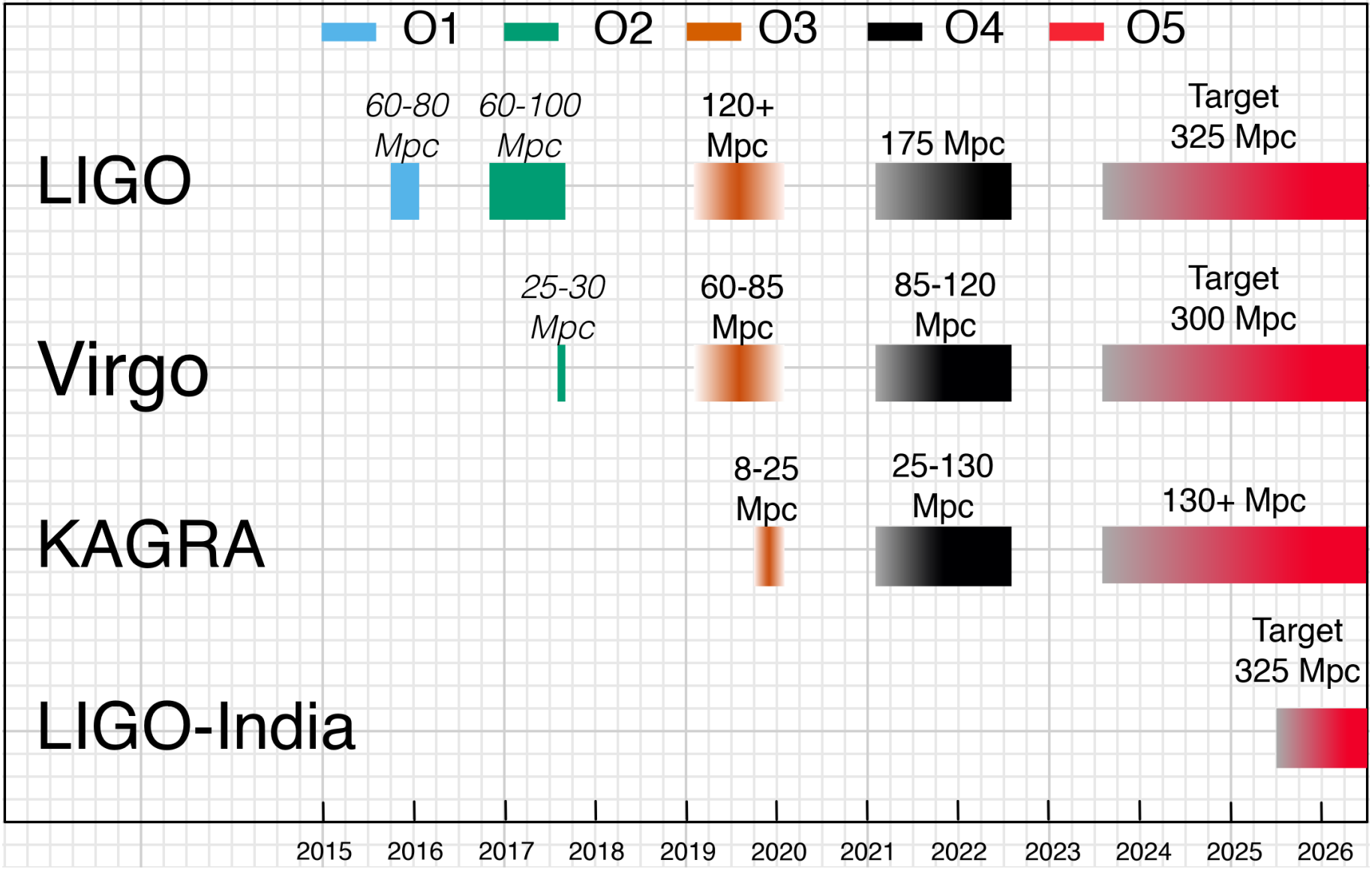
PTEP 2018, 013F01 (2018)

First cryogenic test run (Phase 1)

arXiv:**********

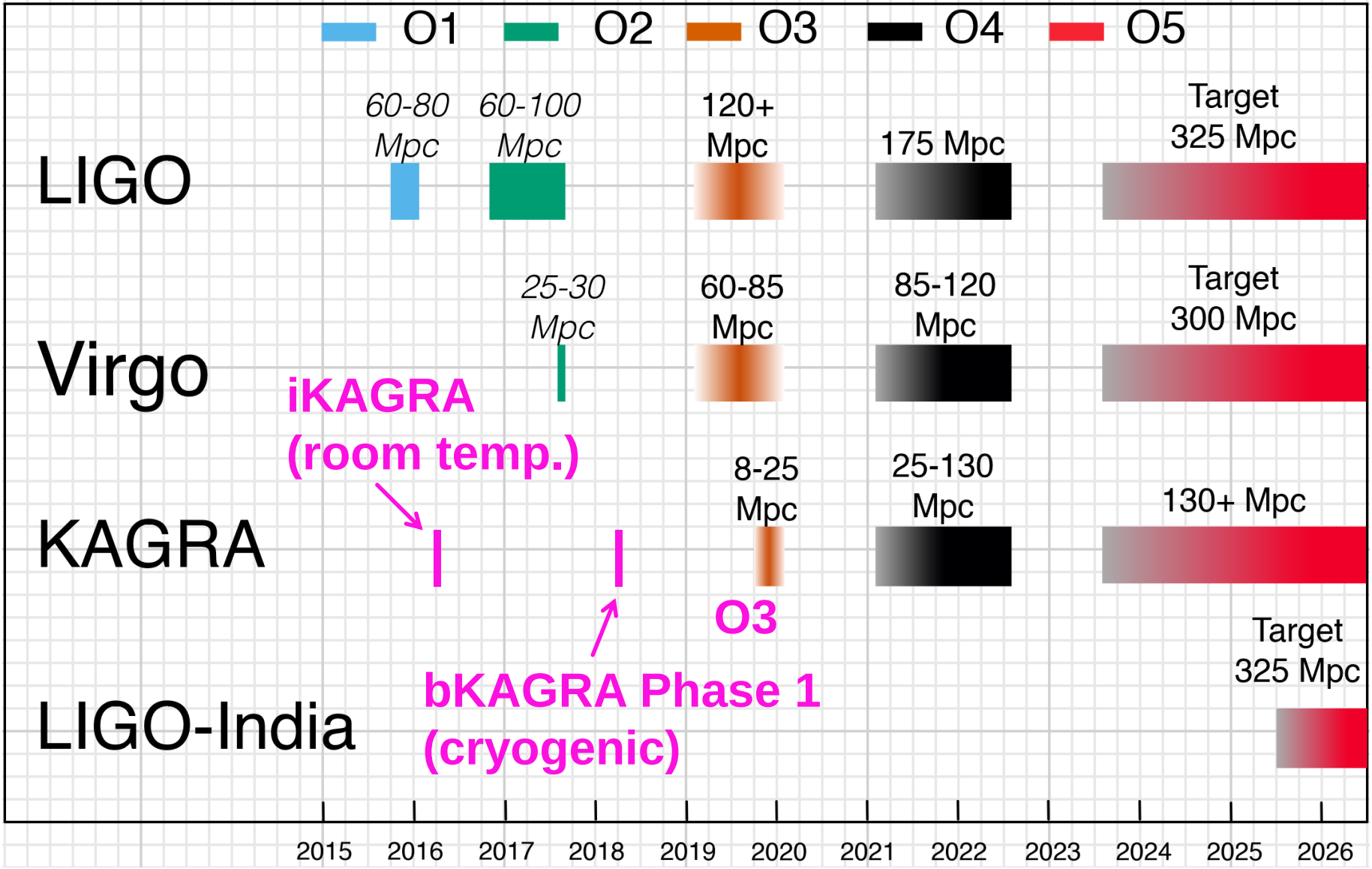
Join observing run O3

Observation Scenario



Living Reviews in Relativity 21, 3 (2018); updated version available from https://git.ligo.org/publications/detectors/obs-scenarios-2018/blob/master/Figures/ObsScen_fig2_v12.pdf

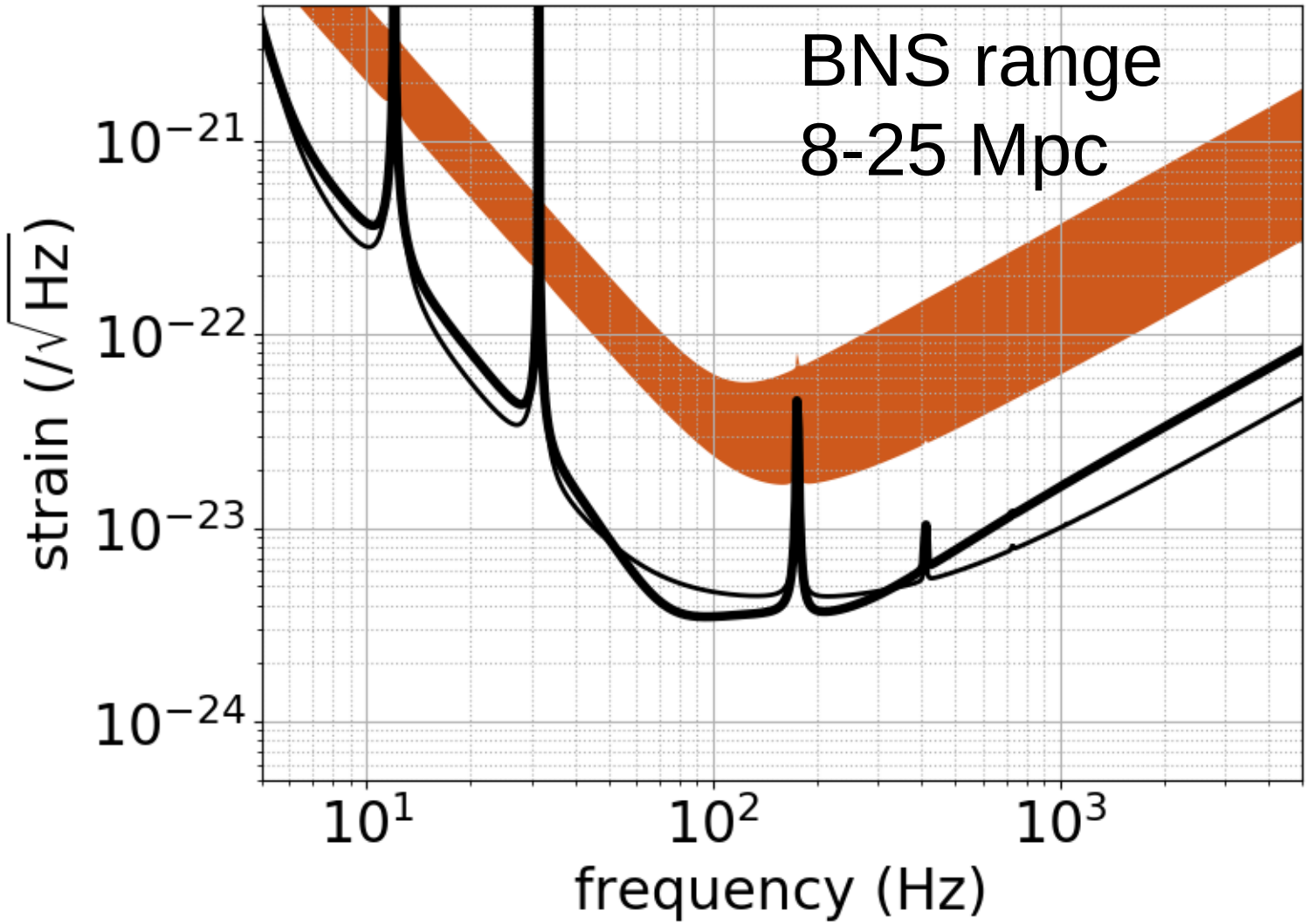
Observation Scenario



Living Reviews in Relativity 21, 3 (2018); updated version available from https://git.ligo.org/publications/detectors/obs-scenarios-2018/blob/master/Figures/ObsScen_fig2_v12.pdf

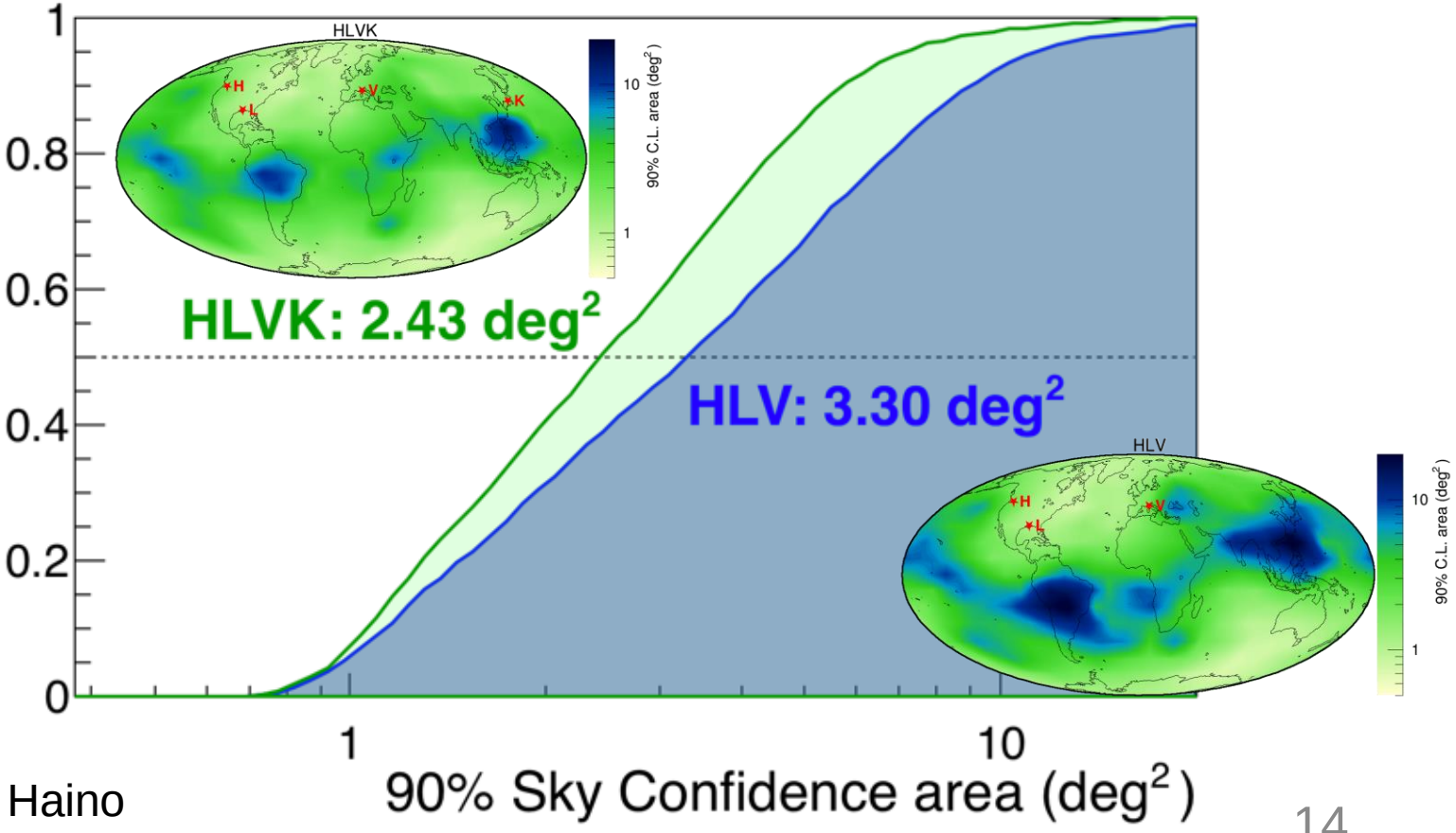
Target Sensitivity for O3

- Aims for 10-30 W input, BRSE with R_SRM = 70%



KAGRA Joining O3

- Improves sky coverage, network duty factor, source parameter estimation
- New test of GR through polarization measurements



Calculation by S. Haino
(GW170817-like binary, L: 120 Mpc, V: 80 Mpc, K: 20 MPc)

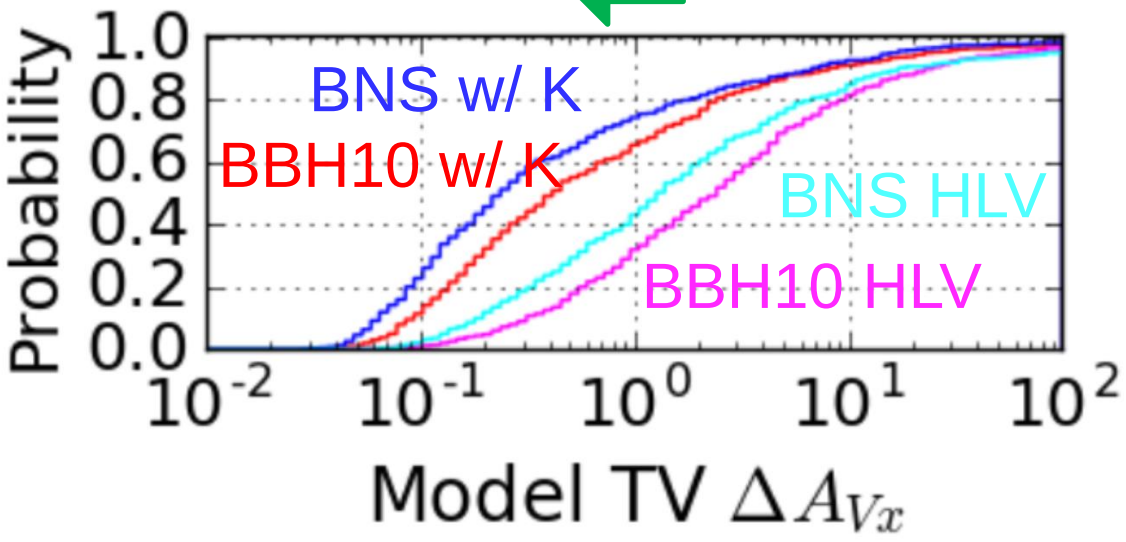
Test of GR with CBC Polarization

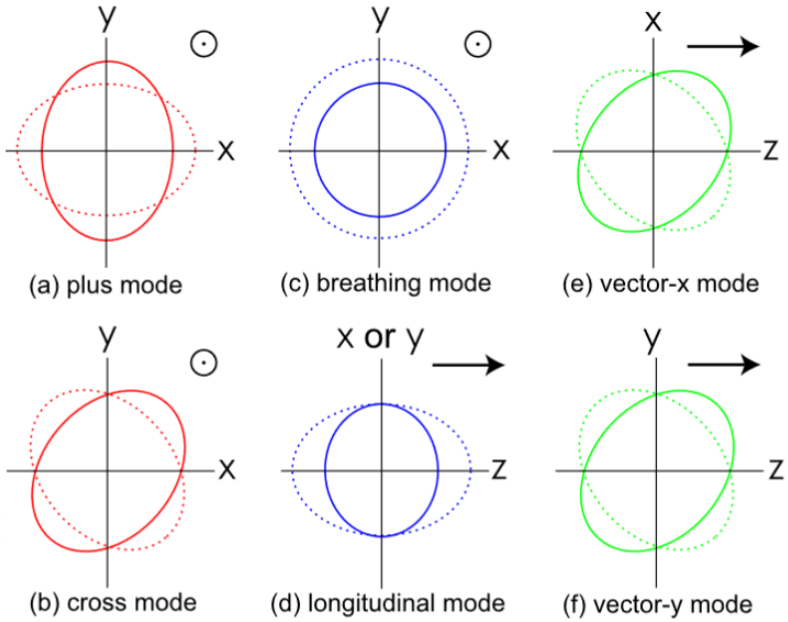
- Fourth detector necessary to distinguish four polarizations

H. Takeda+, PRD 98, 022008 (2018)

- Number of detector matters!

error reduces to < 1 with KAGRA

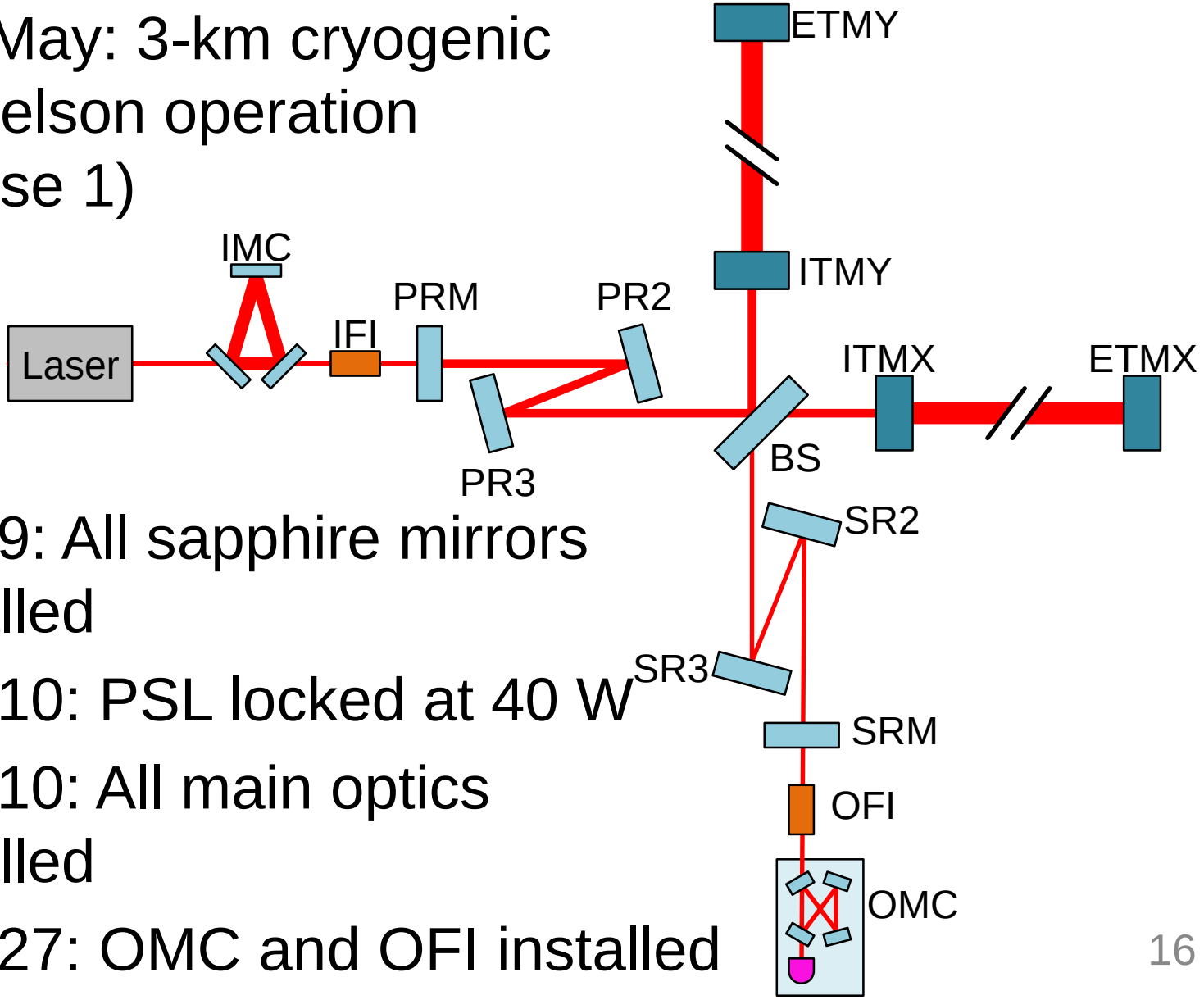




Error in vector-x mode amplitude

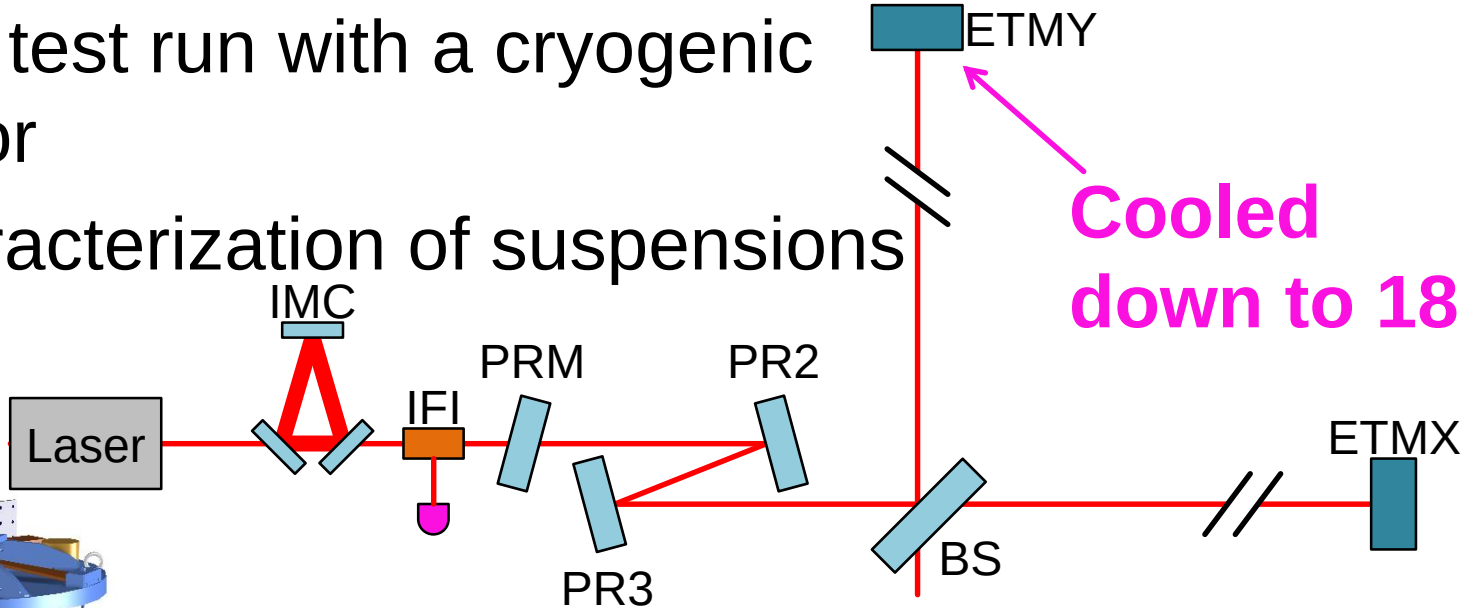
A Lot of Progress in 2018

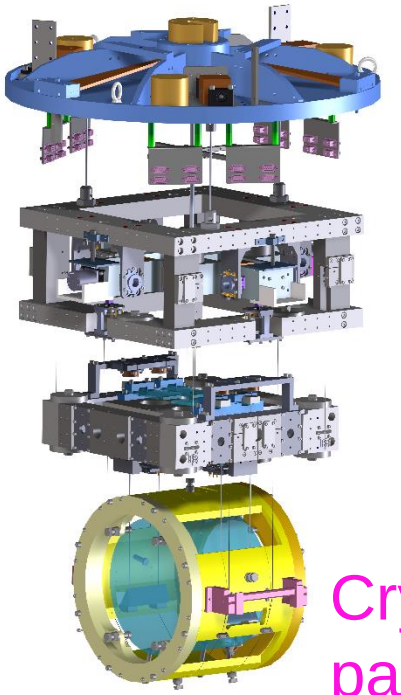
- Apr-May: 3-km cryogenic Michelson operation (Phase 1)
- Nov 9: All sapphire mirrors installed
- Nov 10: PSL locked at 40 W
- Dec 10: All main optics installed
- Dec 27: OMC and OFI installed



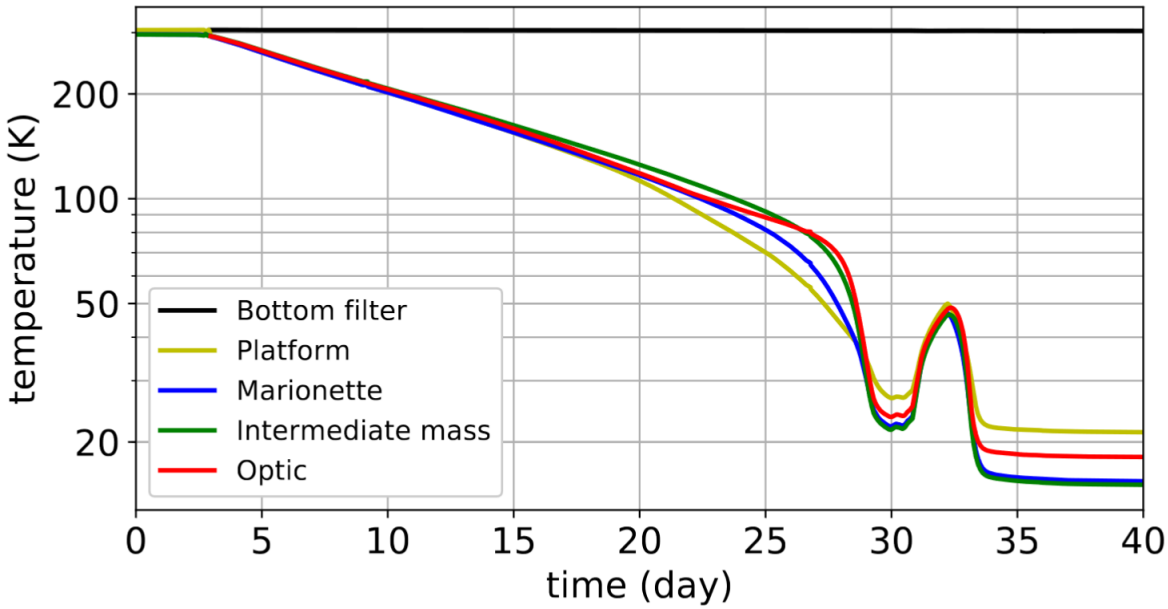
Phase 1 Operation

- First test run with a cryogenic mirror
- Characterization of suspensions



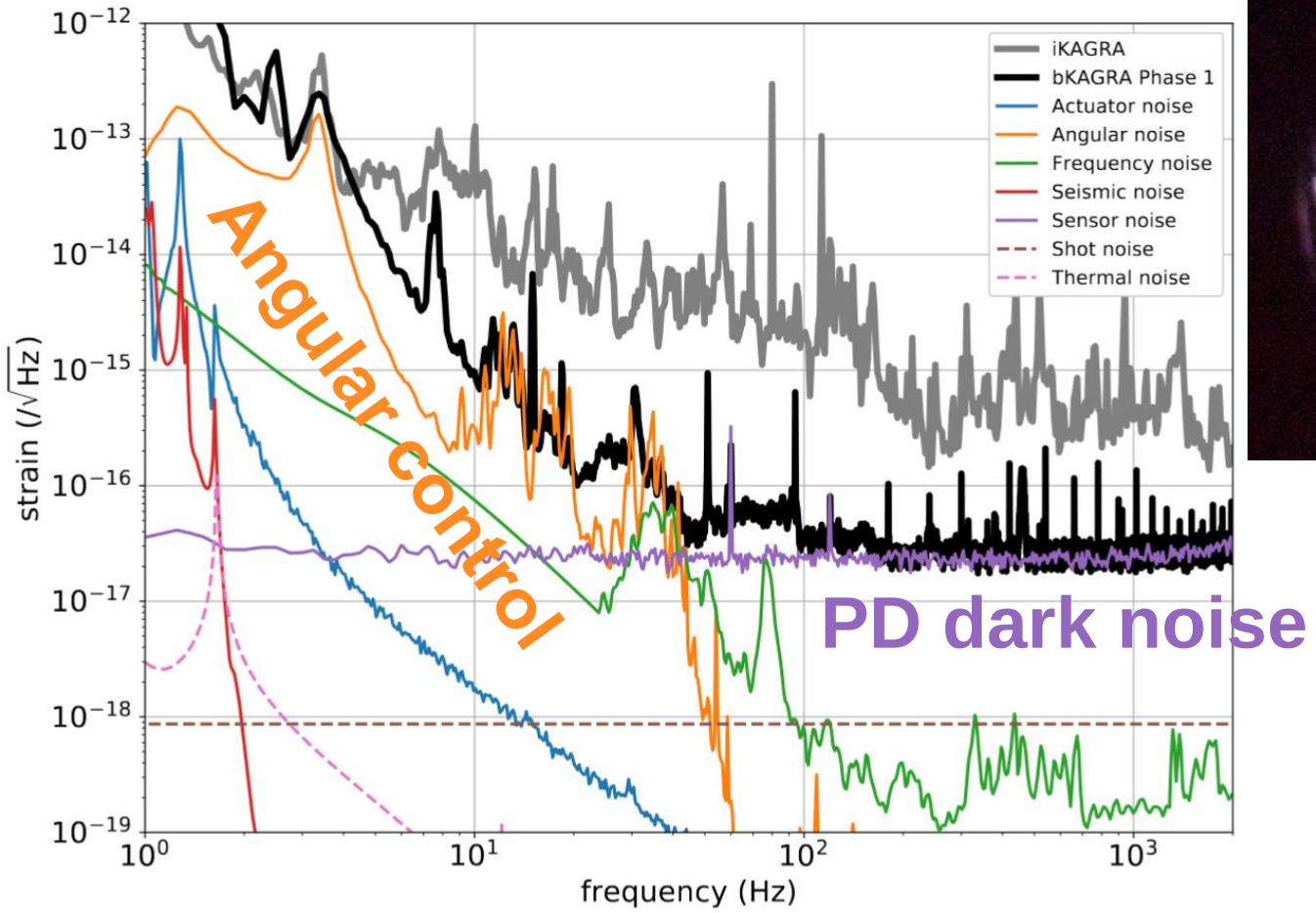


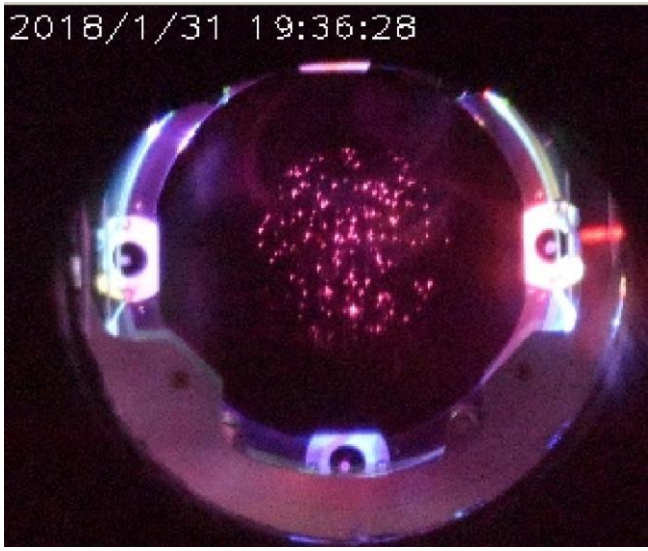
Cryogenic payload



Phase 1 Operation

- Sensitivity at 3e-16 /rtHz @ 100 Hz
- Gained experience in aligning and operating cryogenic interferometer



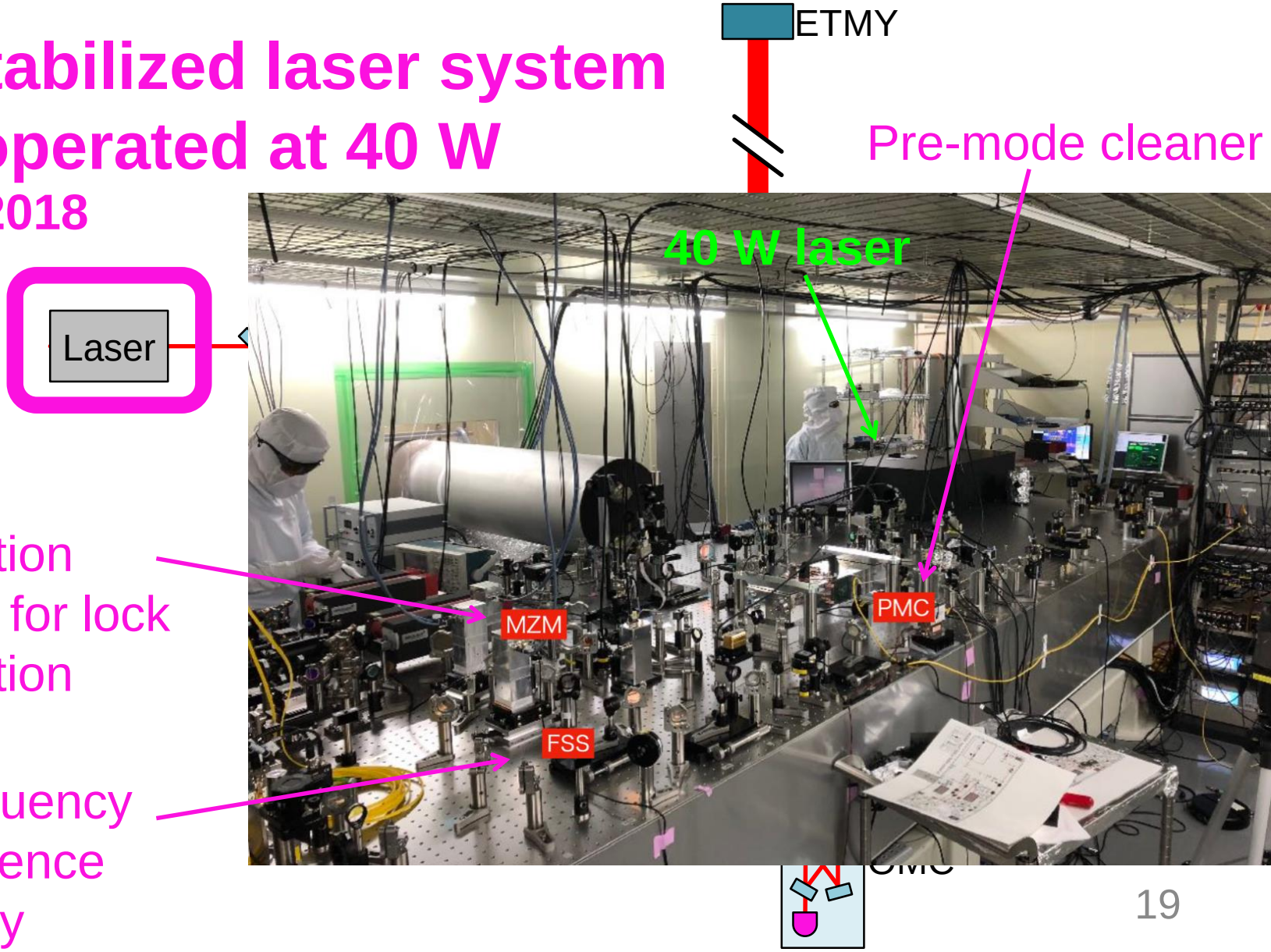


ETMY taken by telephoto camera

Installation Progress: PSL

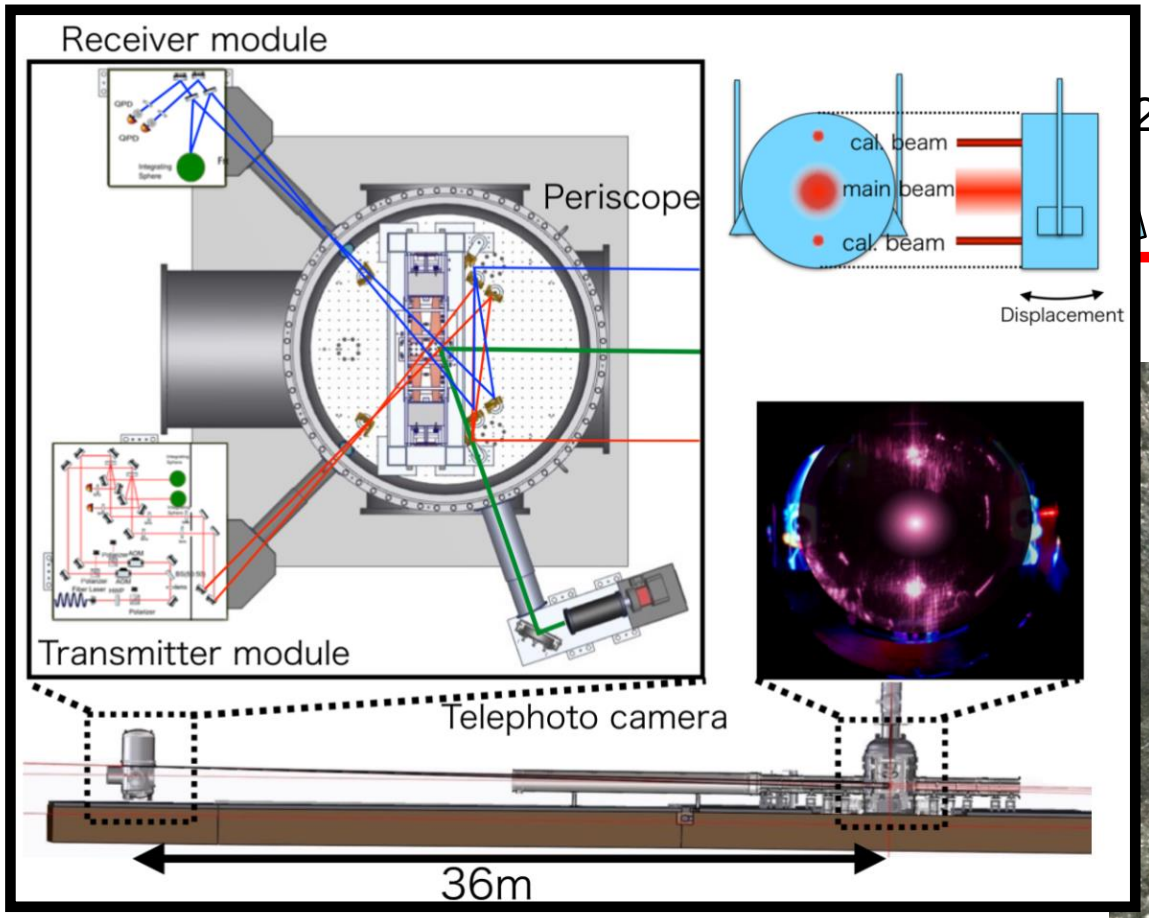
Pre-stabilized laser system fully operated at 40 W

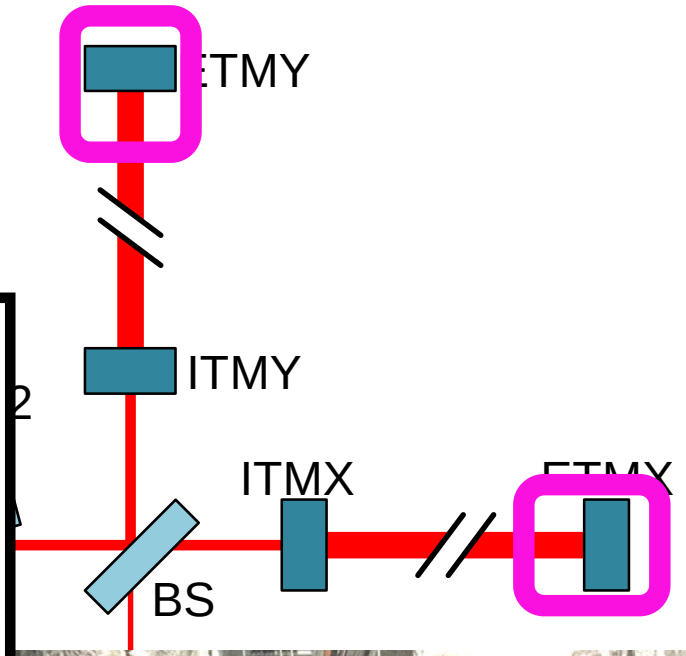
Nov 9, 2018

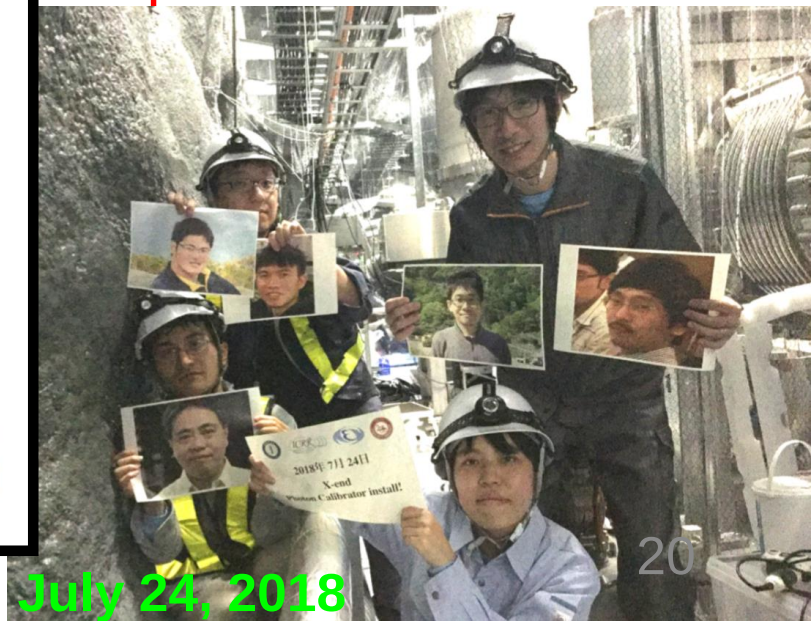


Installation Progress: PCal

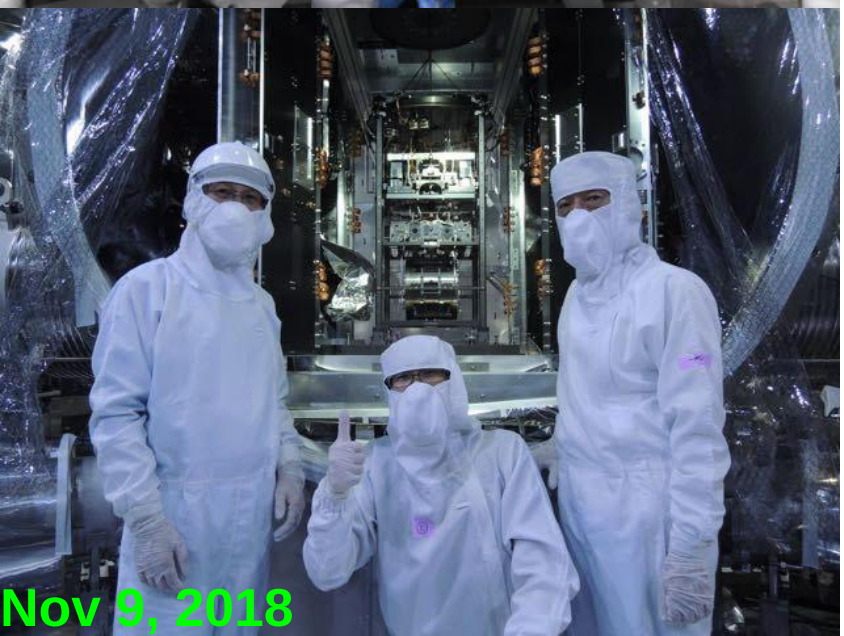
Photon calibrator installed to both ends







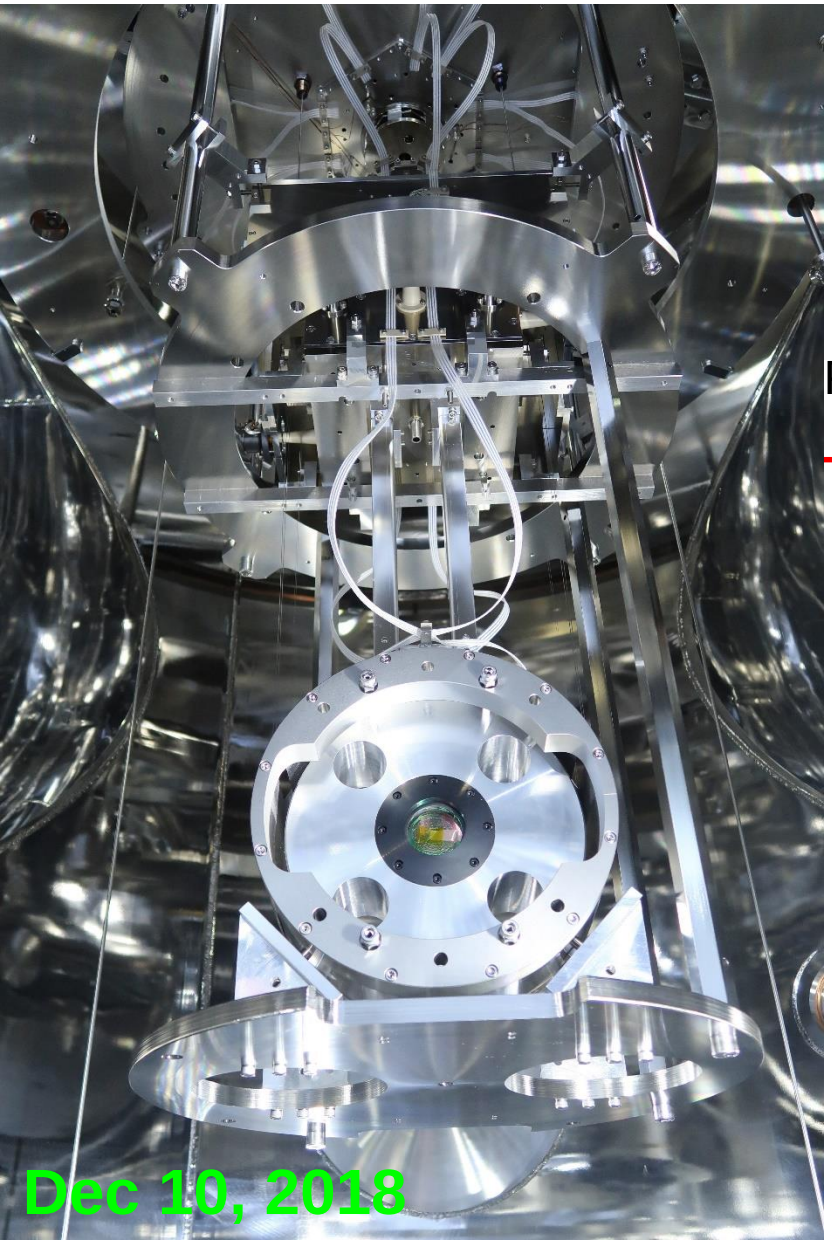
Installation Progress: Cryopayload

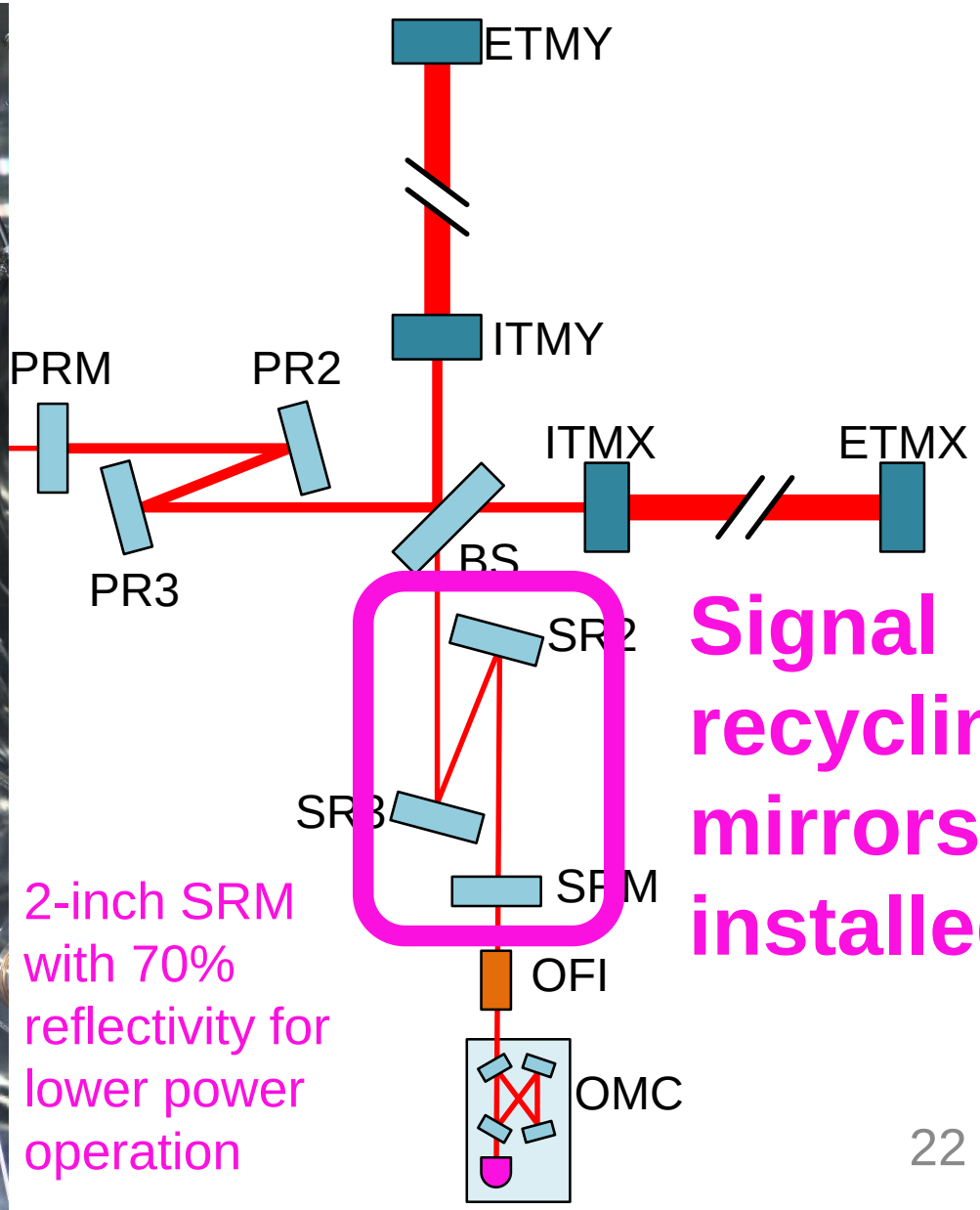


Nov 9, 2018

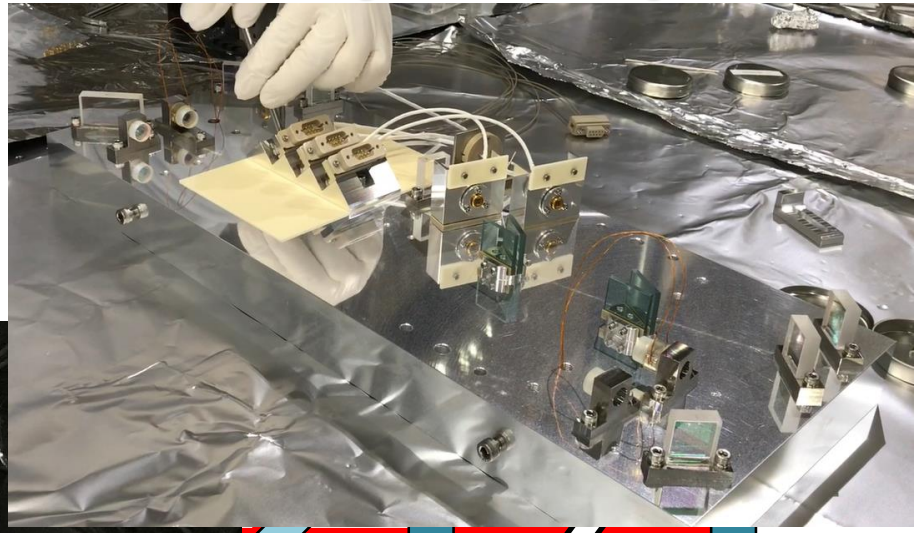
ETMX heat link vibration isolation in progress

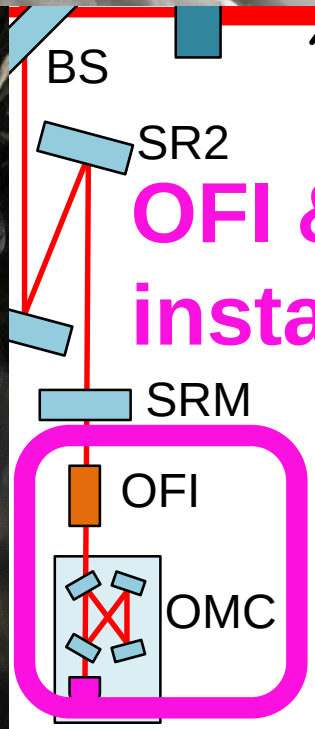
Installation Progress: SR Mirrors





Installation Progress: Output Optics



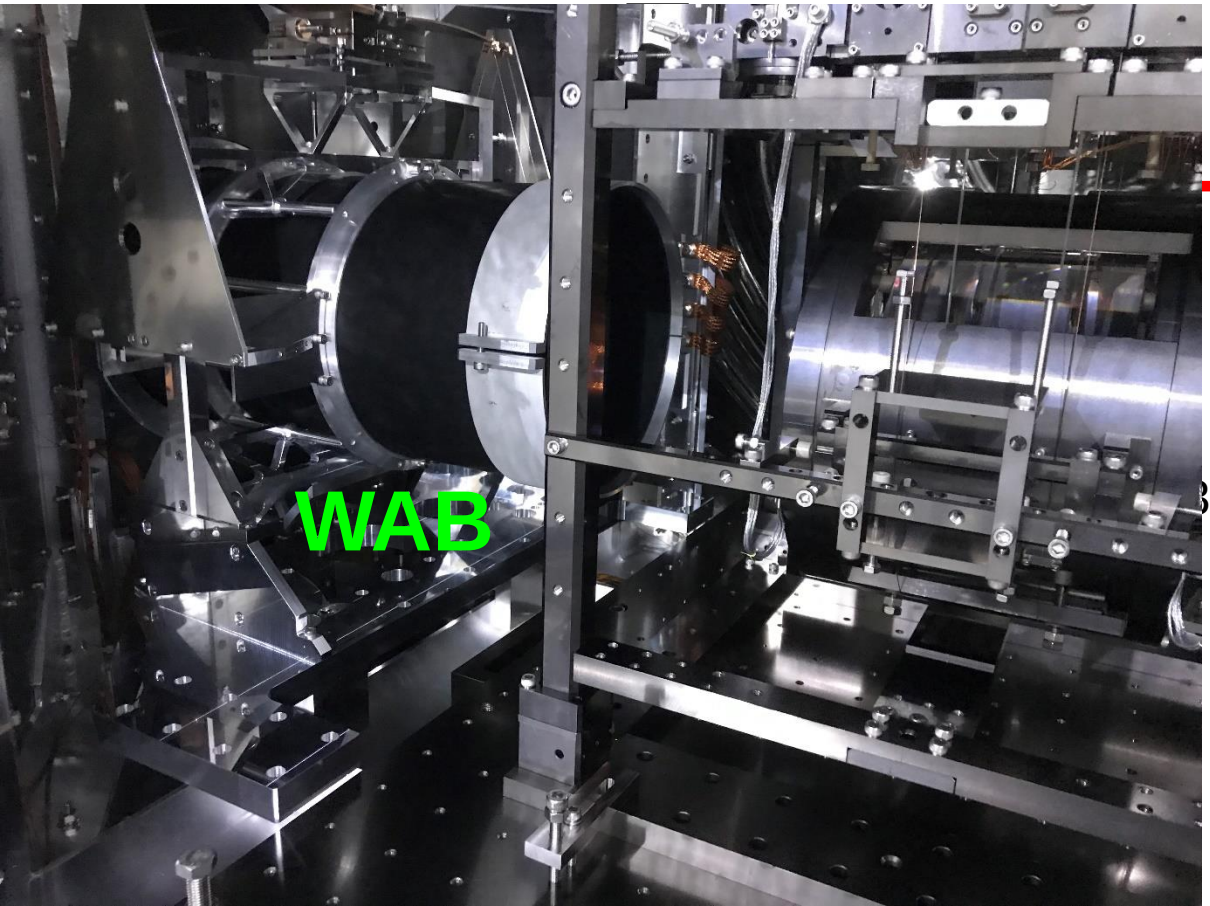


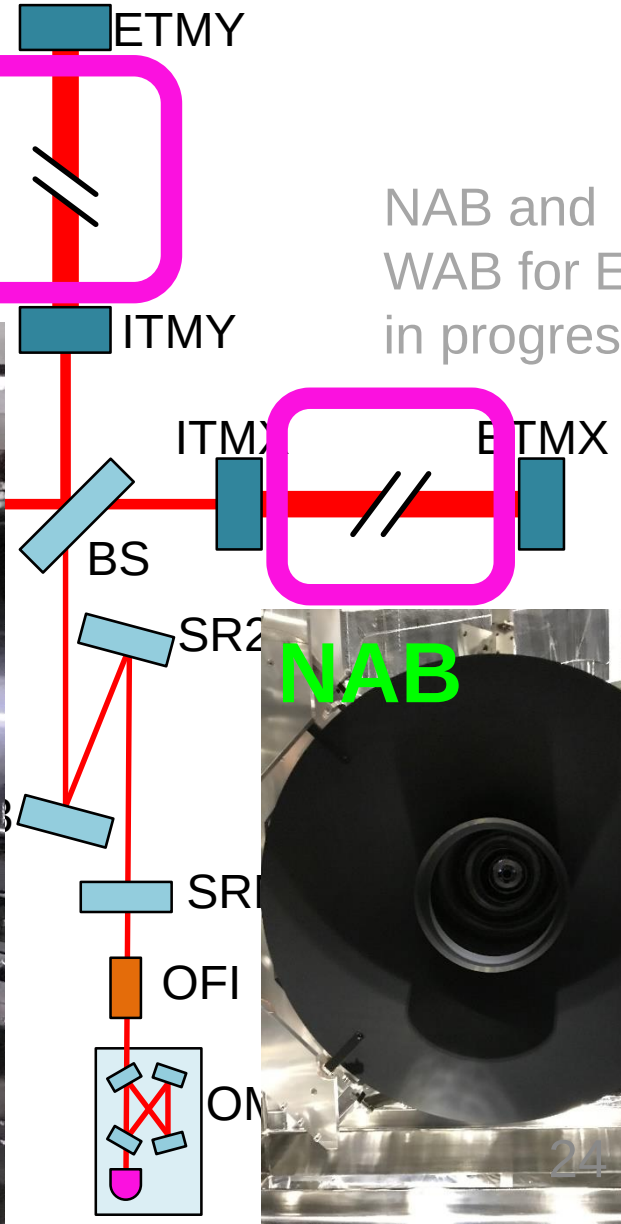
OFI & OMC installed

OSTM in progress

Installation Progress: Baffles

Narrow angle baffles,
Wide angle baffles
3 of 4 installed



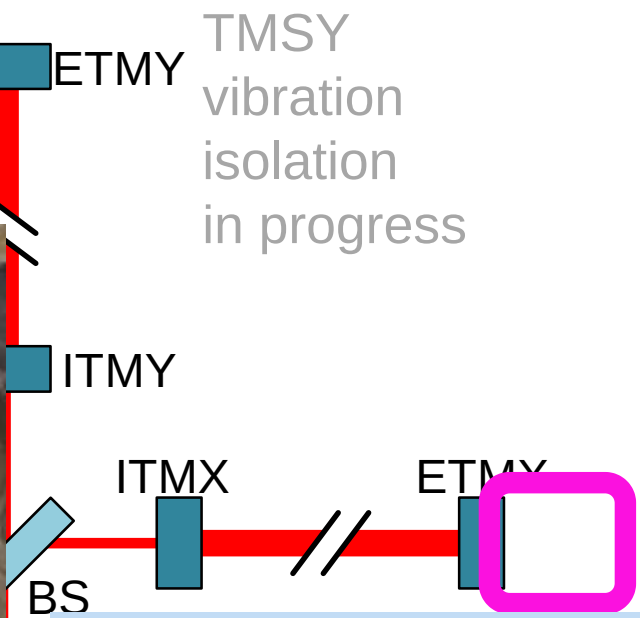


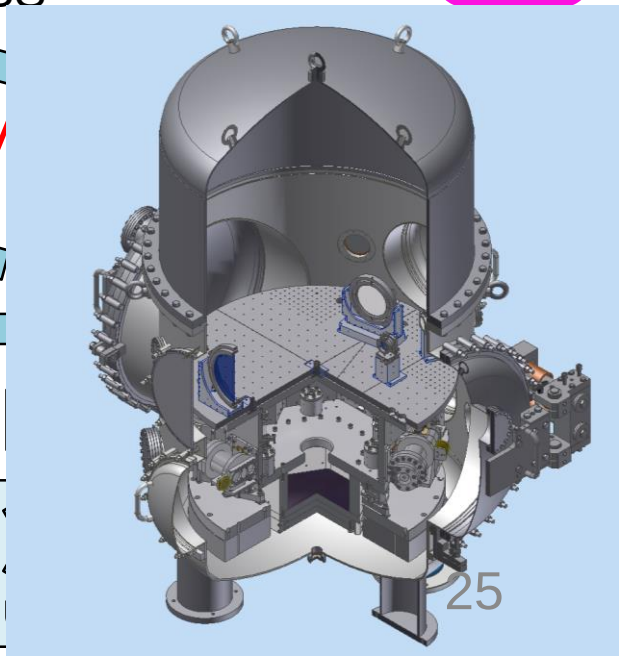
NAB and
WAB for EX
in progress

Installation Progress: Trans Mons

Both transmission monitor system installed

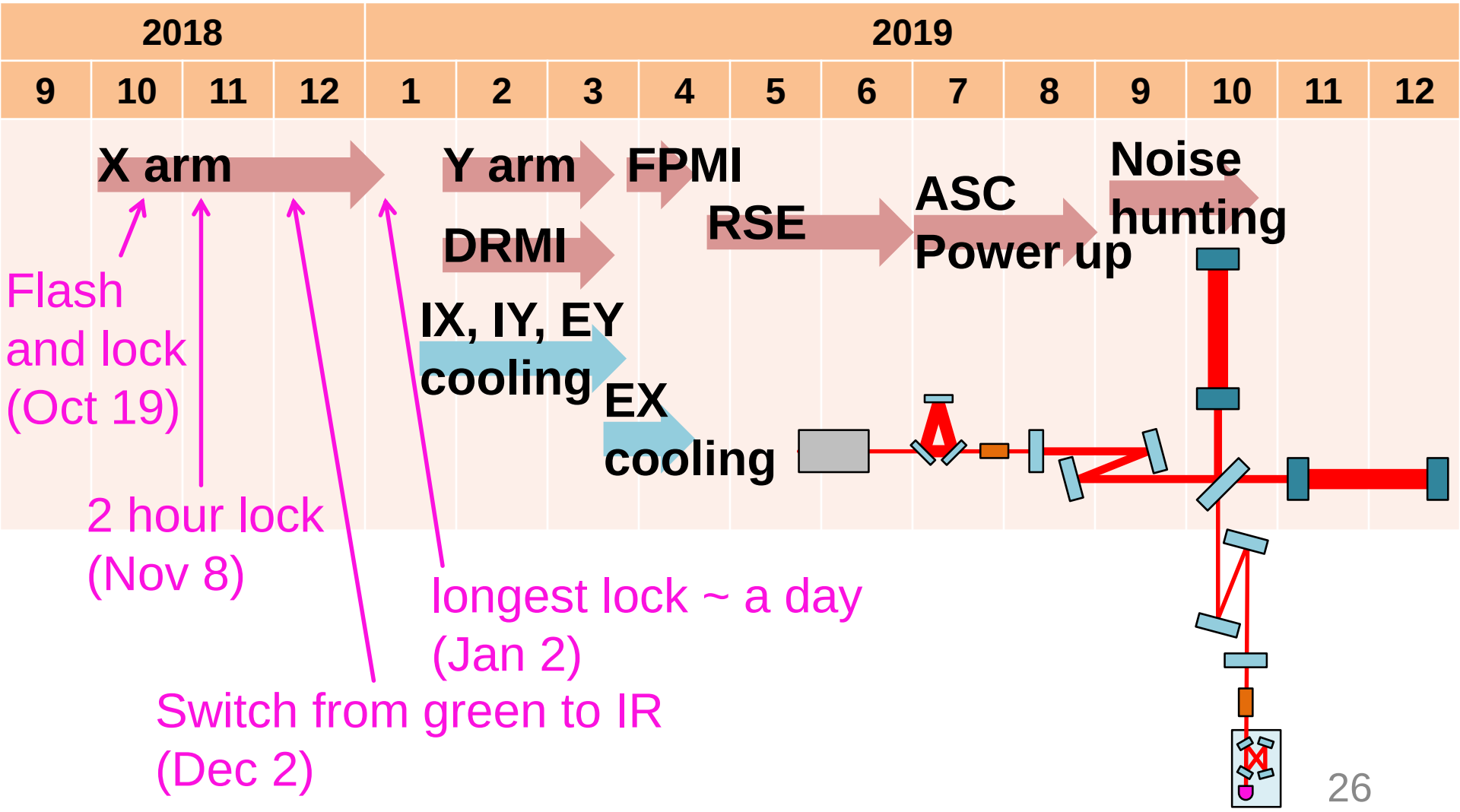
Oct 1, 2018





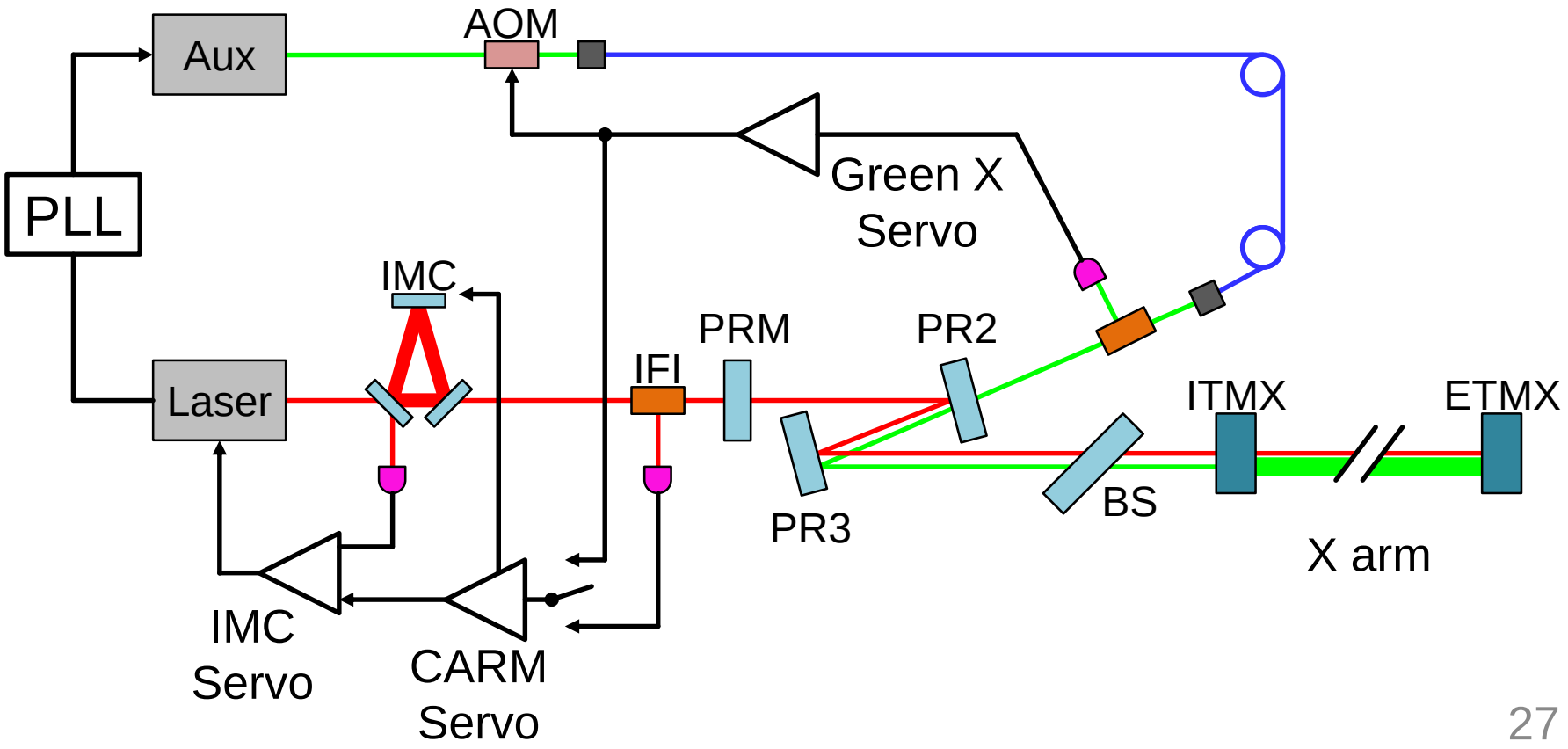
Commissioning Schedule

- X-arm commissioning completed



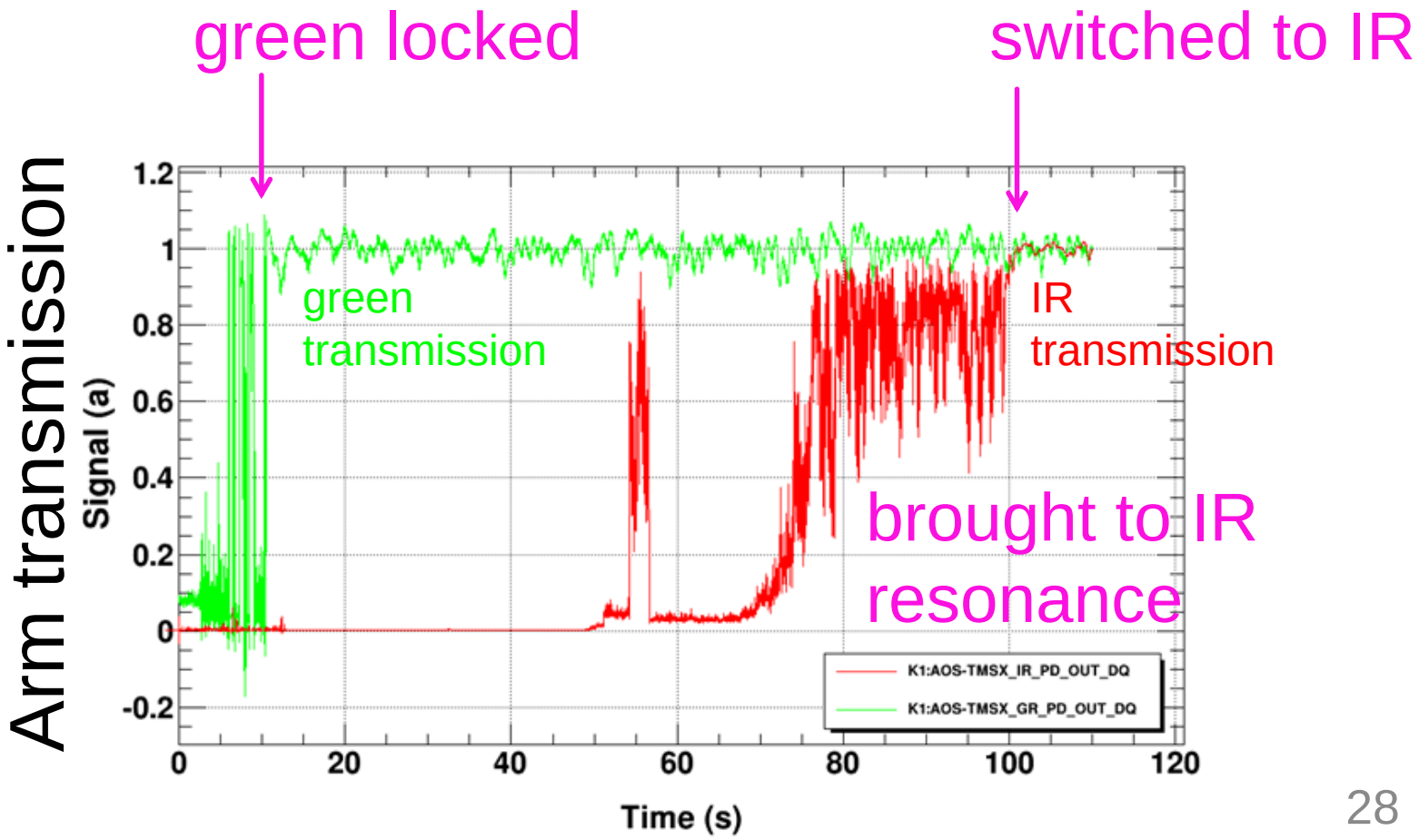
X-arm Commissioning

- First test of arm length stabilization system using green beam
- Simpler configuration than aLIGO



X-arm Commissioning

- Successfully switched directly from green lock to IR lock (RMS 8 Hz < FWHM 33 Hz in IR)



X-arm Commissioning

- Successfully switched directly from green lock to IR lock (RMS 8 Hz < FWHM 33 Hz in IR)

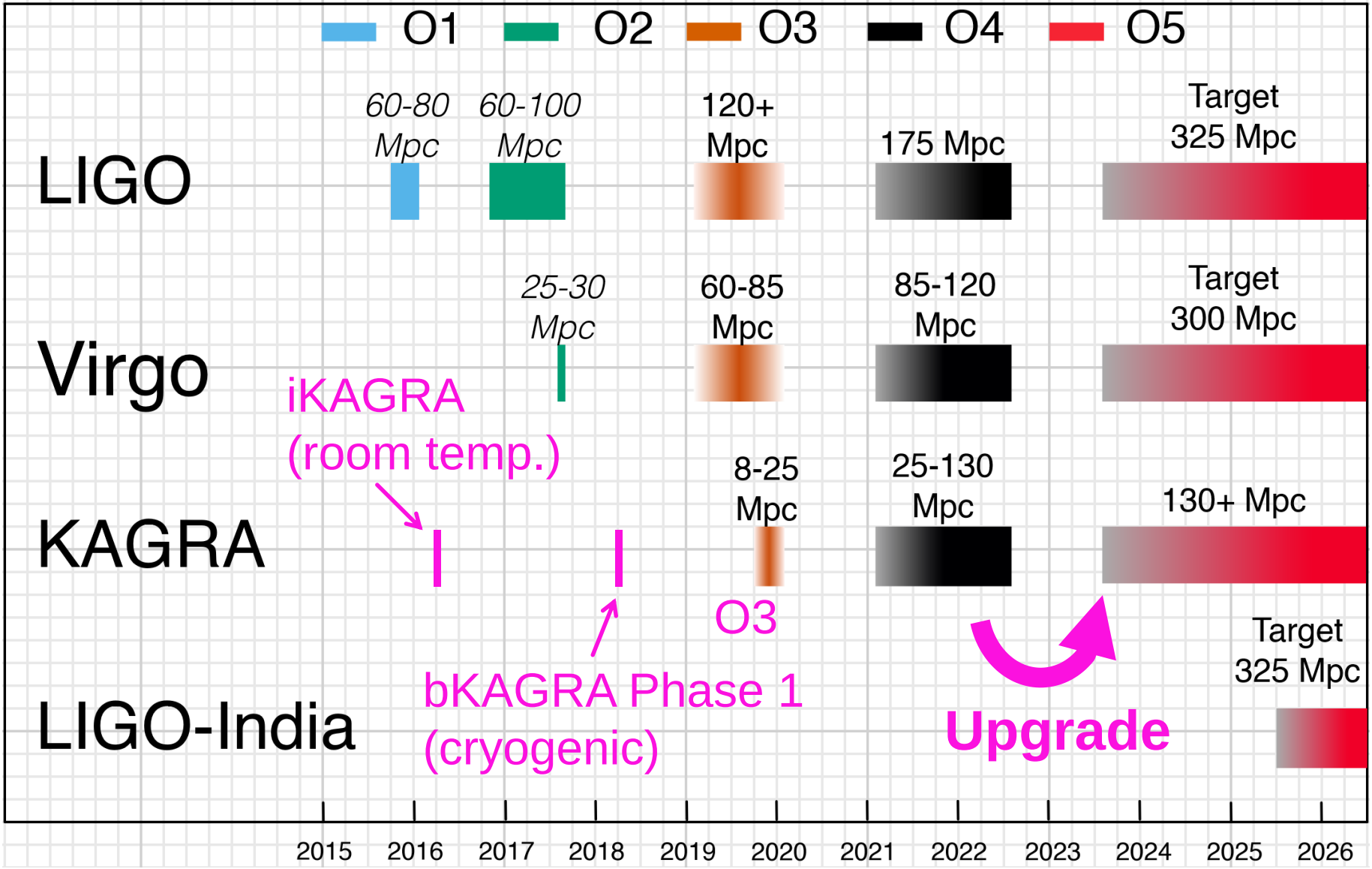
NOISE BUDGET

X-arm Characterization

- As expected, less than 100 ppm roundtrip loss

	Design	Measured
Finesse	1530	1411±2±30
ITMX transmission	0.4 %(+0.1 %)	0.44 %
Mode matching		91±1 %
Roundtrip loss	< 100 ppm	86±3 ppm
Arm length	3000 m	2999.990(2) m
Transverse mode spacing	34.80 kHz	34.79(5) kHz
Finesse (Green)	52	41.0±0.3
Mode matching (Green)		~70 %

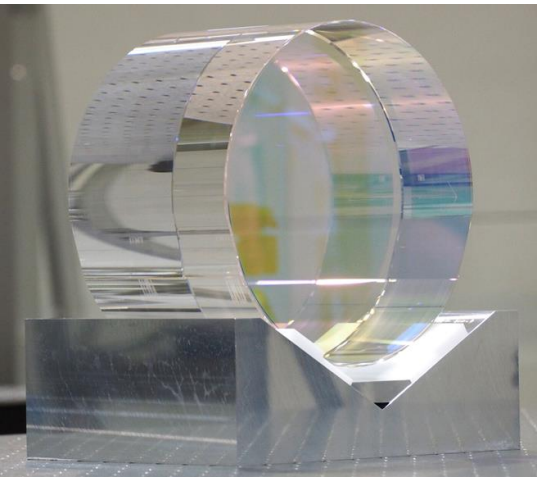
Observation Scenario



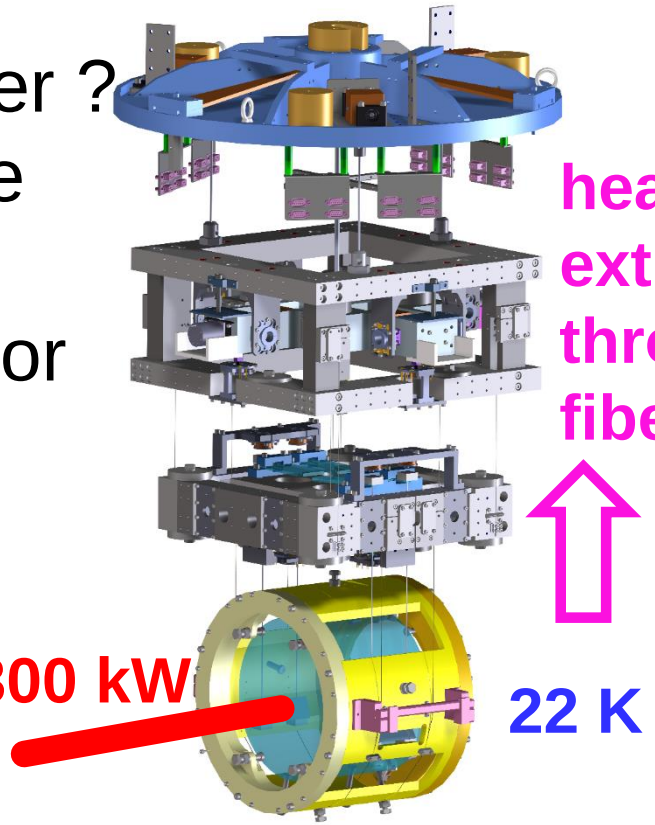
Updated version of Living Reviews in Relativity 21, 3 (2018); available from https://git.ligo.org/publications/detectors/obs-scenarios-2018/blob/master/Figures/ObsScen_fig2_v12.pdf

KAGRA Upgrade Study

- Upgrade study *formally* started in December 2018
- Future Planning Committee formulated
- Science case study and technical feasibility study on going
  - High power or low power ?
  - Sapphire test mass size
  - Squeezing
  - KAGRA as a 4th detector

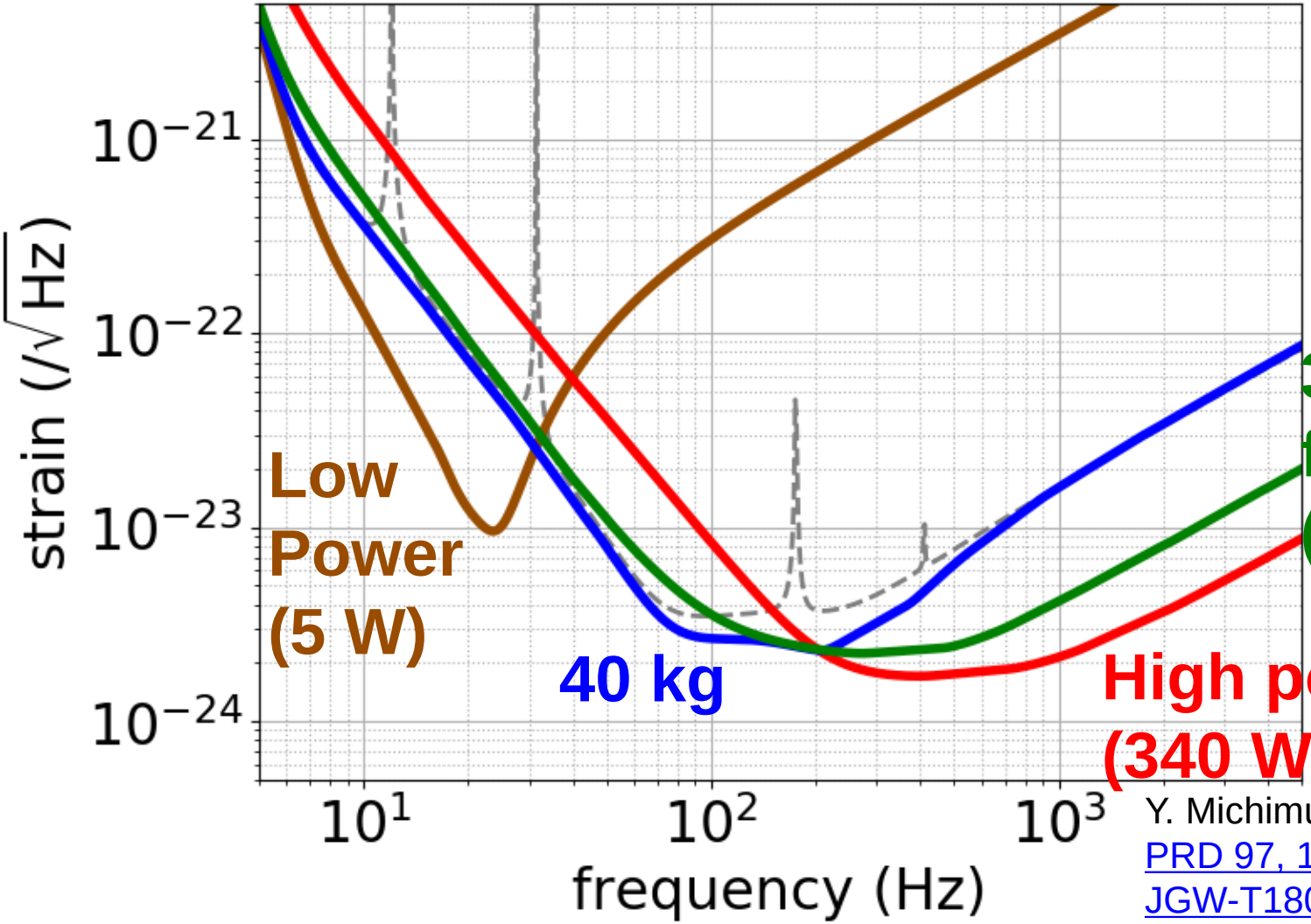


Φ22 cm x t 15 cm
22.8 kg



Possible Near Term Upgrade Plans

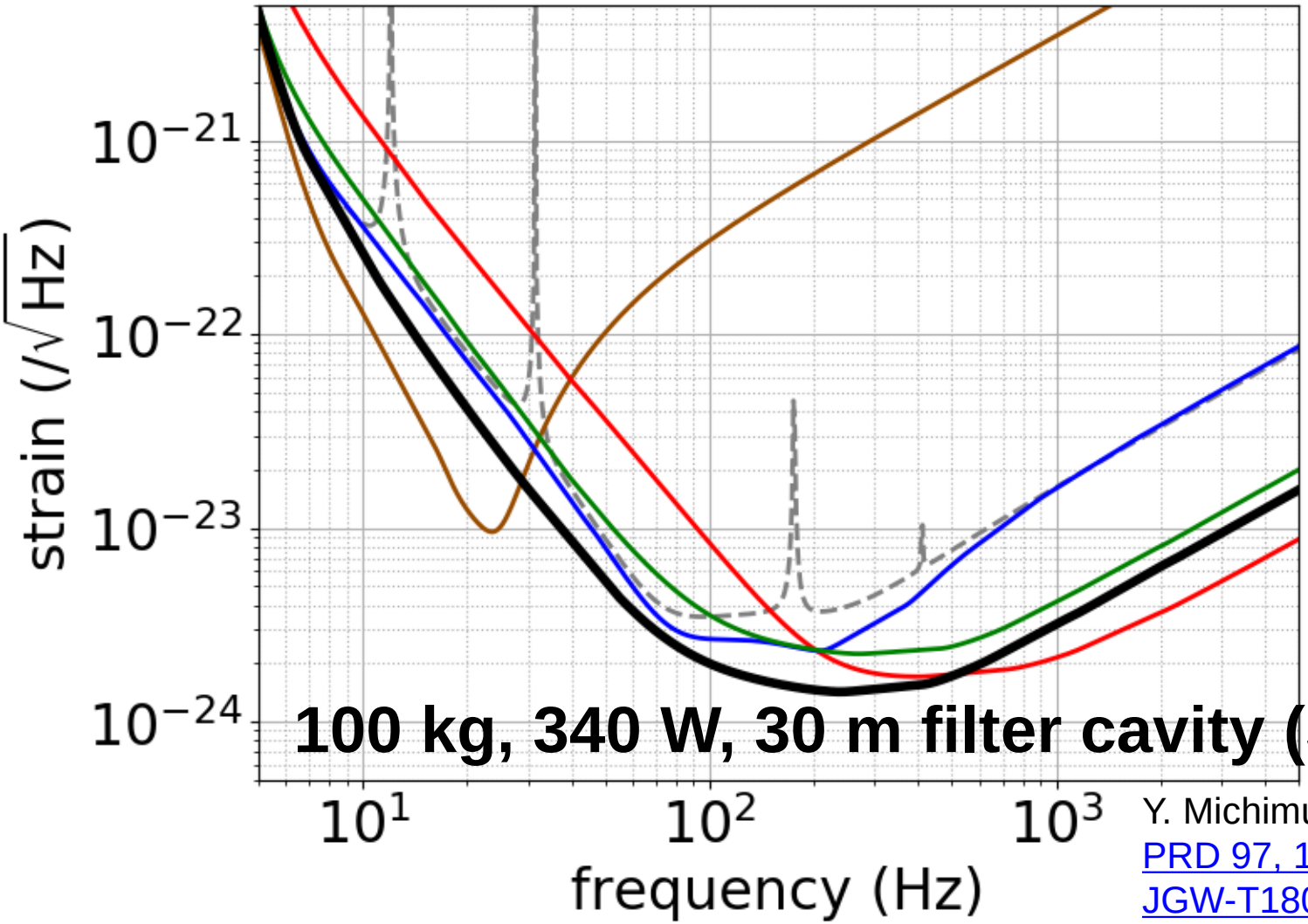
- Based on technical feasibility, facility and budget constraints



Y. Michimura+, PRD 97, 122003 (2018); JGW-T1809537

Possible Longer Term Upgrade

- Reaches BNS range of 300 Mpc by combining technologies (twofold improvement)

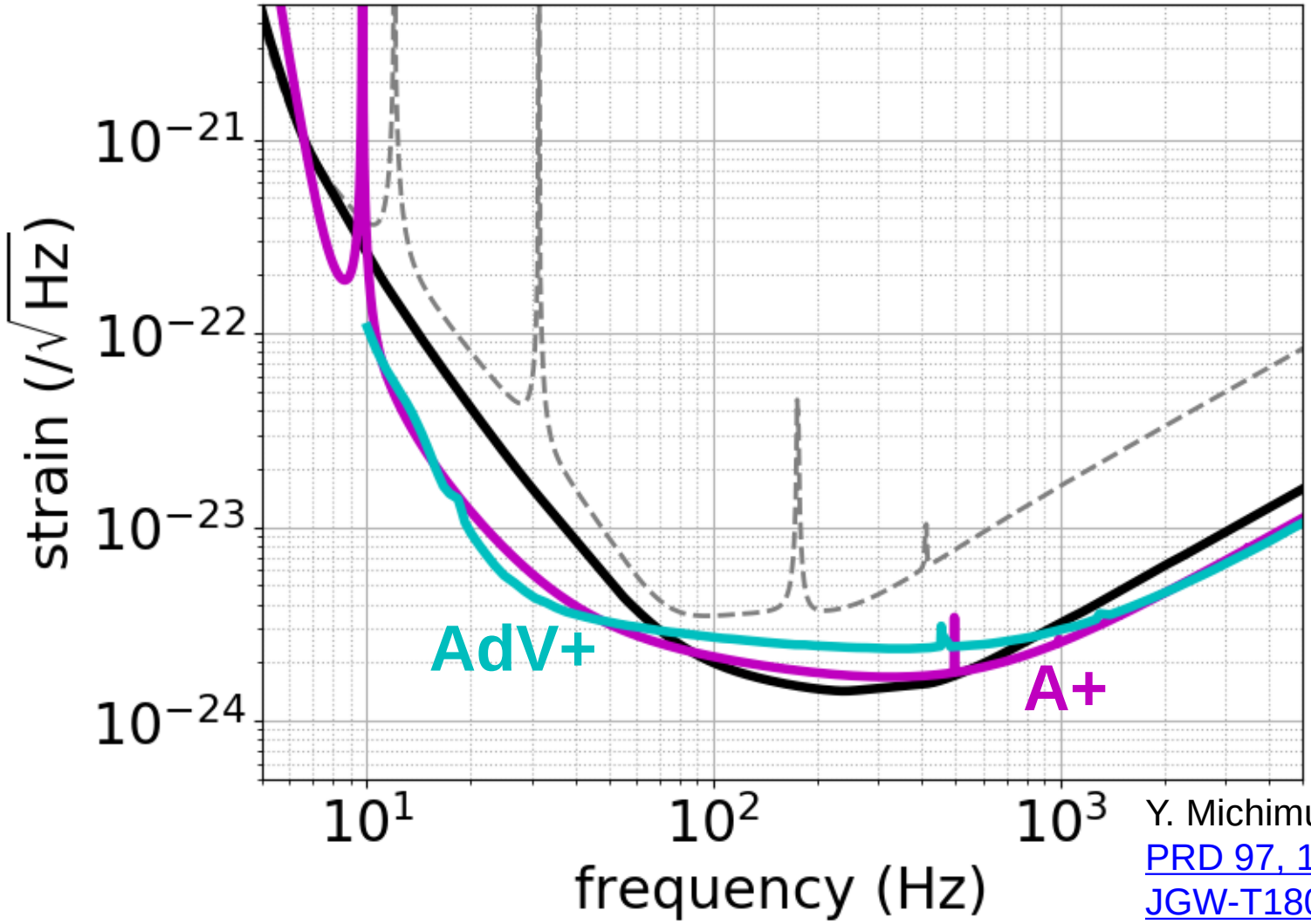


100 kg, 340 W, 30 m filter cavity (5 dB SQZ)

Y. Michimura+, PRD 97, 122003 (2018); JGW-T1809537

Possible Longer Term Upgrade

- Comparable to A+ and AdV+



Y. Michimura+, PRD 97, 122003 (2018); JGW-T1809537

Summary

- KAGRA is an underground cryogenic GW detector

- Almost all the installation works completed
- X-arm commissioning successfully done
- So far so good for O3

- KAGRA upgrade study formally started
- Different approach for the upgrade might be required for KAGRA

Supplementary Slides

2G/2G+ Parameter Comparison

	KAGRA	AdVirgo	aLIGO	A+	Voyager
Arm length [km]	3	3	4	4	4
Mirror mass [kg]	23	42	40	80	200
Mirror material	Sapphire	Silica	Silica	Silica	Silicon
Mirror temp [K]	22	295	295	295	123
Sus fiber	35cm Sap.	70cm SiO_2	60cm SiO_2	60cm SiO_2	60cm Si
Fiber type	Fiber	Fiber	Fiber	Fiber	Ribbon
Input power [W]	67	125	125	125	140
Arm power [kW]	340	700	710	1150	3000
Wavelength [nm]	1064	1064	1064	1064	2000
Beam size [cm]	3.5 / 3.5	4.9 / 5.8	5.5 / 6.2	5.5 / 6.2	5.8 / 6.2
SQZ factor	0	0	0	6	8
F. C. length [m]	none	none	none	16	300

LIGO parameters from LIGO-T1600119, AdVirgo parameters from JPCS 610, 01201 (2015)

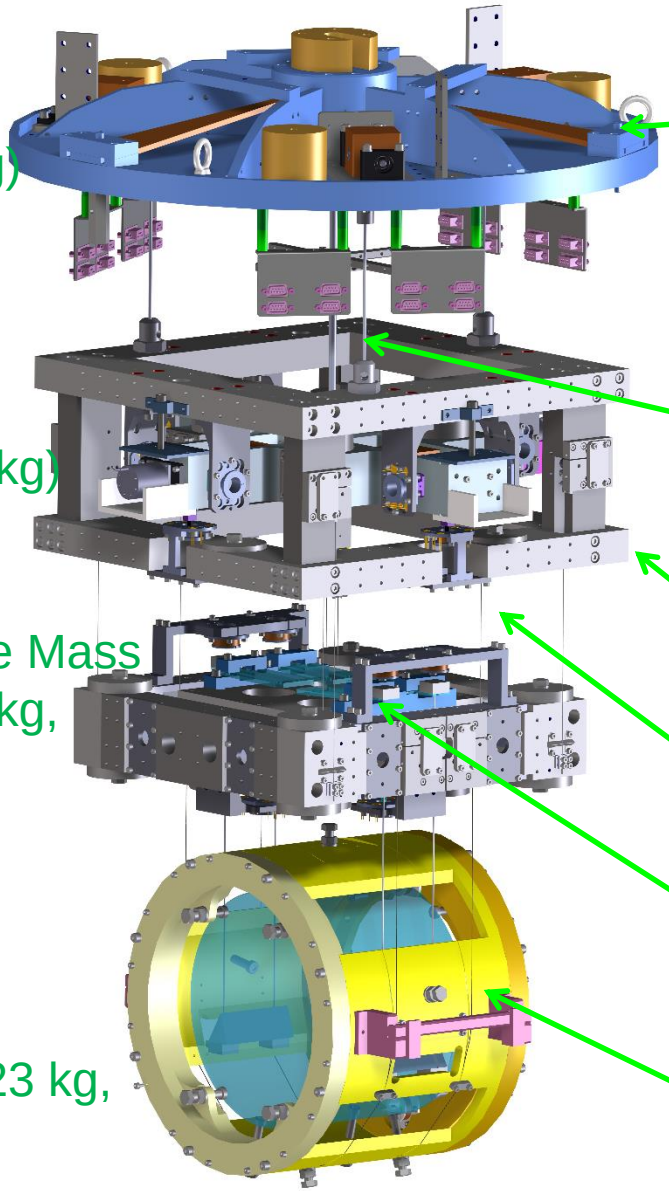
KAGRA Detailed Parameters

K. Komori *et al.*, JGW-T1707038

- **Optical parameters**
  - Mirror transmission: 0.4 % for ITM, 10 % for PRM, 15.36 % for SRM
  - Power at BS: 674 W
  - Detune phase: 3.5 deg (DRSE case)
  - Homodyne phase: 135.1 deg (DRSE case)
- **Sapphire mirror parameters**
  - TM size: 220 mm dia., 150 mm thick
  - TM mass: 22.8 kg
  - TM temperature: 22 K
  - Beam radius at ITM: 3.5 cm
  - Beam radius at ETM: 3.5 cm
  - Q of mirror substrate: 1e8
  - Coating: tantala/silica
  - Coating loss angle: 3e-4 for silica, 5e-4 for tantala
  - Number of layers: 22 for ITM, 40 for ETM
  - Coating absorption: 0.5 ppm
  - Substrate absorption: 50 ppm/cm
- **Suspension parameters**
  - TM-IM fiber: 35 cm long, 1.6 mm dia.
  - IM temperature: 16 K
  - Heat extraction: 5800 W/m/K at 20 K
  - Loss angle: 5e-6/2e-7/7e-7 for CuBe fiber/sapphire fiber/sapphire blade
- **Inspiral range calculation**
  - SNR=8, fmin=10 Hz, sky average constant 0.442478
- Seismic noise curve includes vertical coupling, vibration from heatlinks and Newtonian noise from surface and bulk

KAGRA Cryopayload

Figure by T. Ushiba and A. Hagiwara



Platform
(SUS, 65 kg)

3 CuBe blade springs

Marionette
(SUS, 22.5 kg)

MN suspended by 1 Maraging steel fiber
(35 cm long, 2-7mm dia.)
MRM suspended by 3 CuBe fibers

Heat link attached to MN

Intermediate Mass
(SUS, 20.1 kg,
16 K)

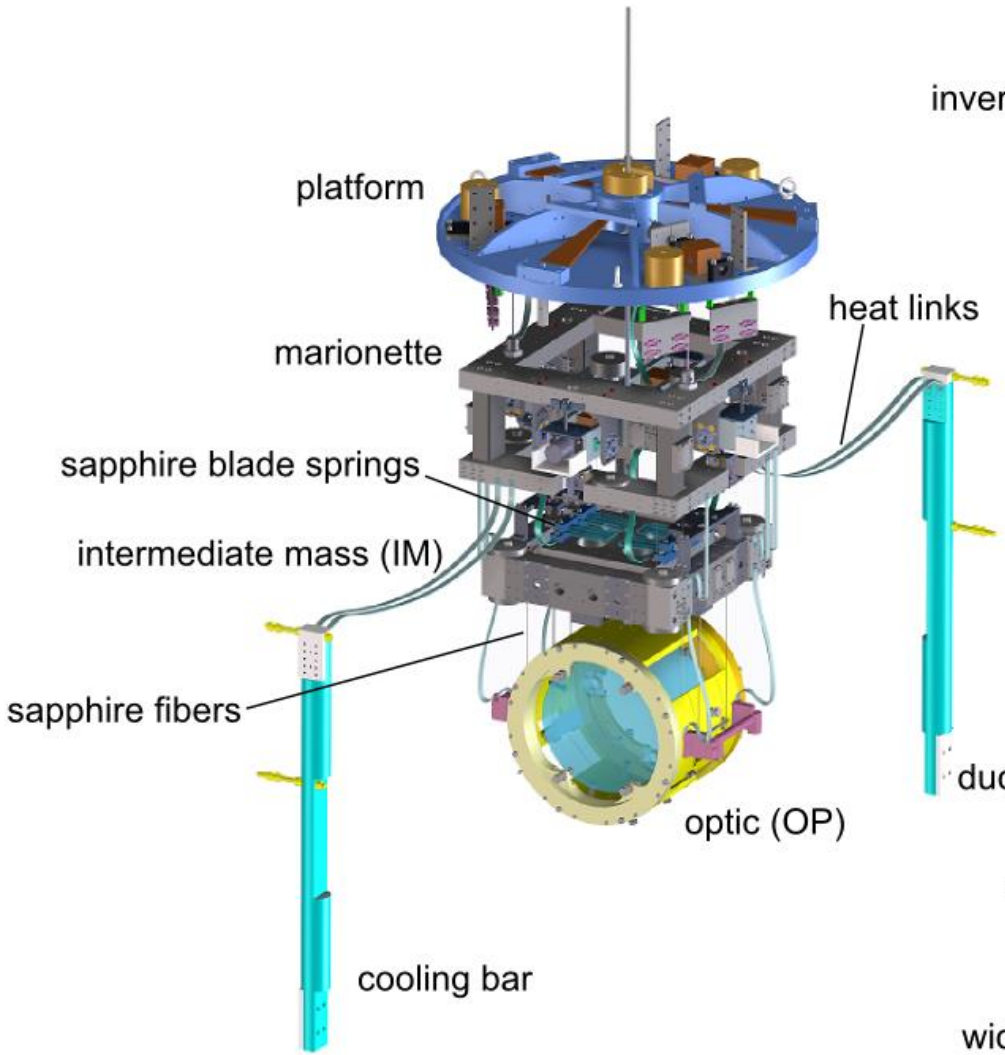
IM suspended by 4 CuBe fibers
(24 cm long, 0.6 mm dia)
IRM suspended by 4 CuBe fibers

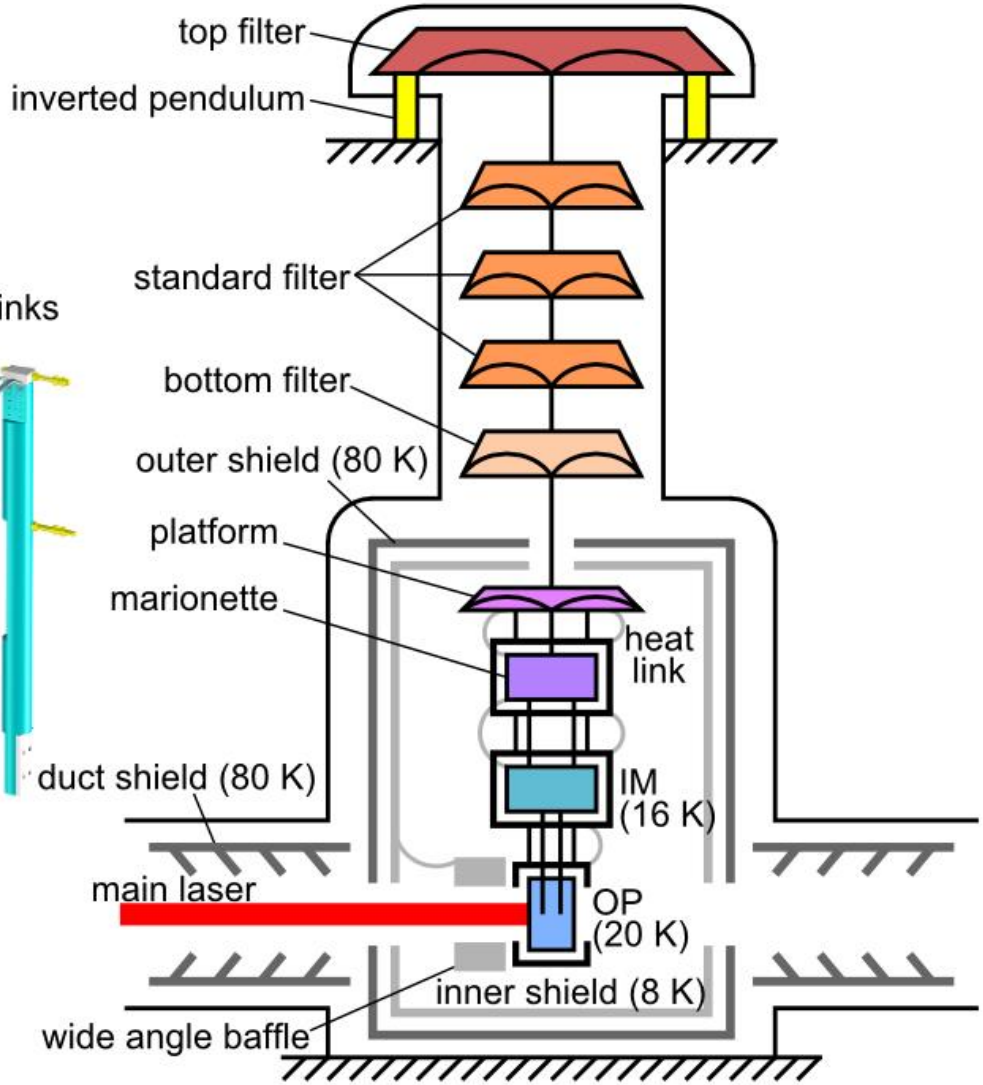
4 sapphire blades

Test Mass
(Sapphire, 23 kg,
22 K)

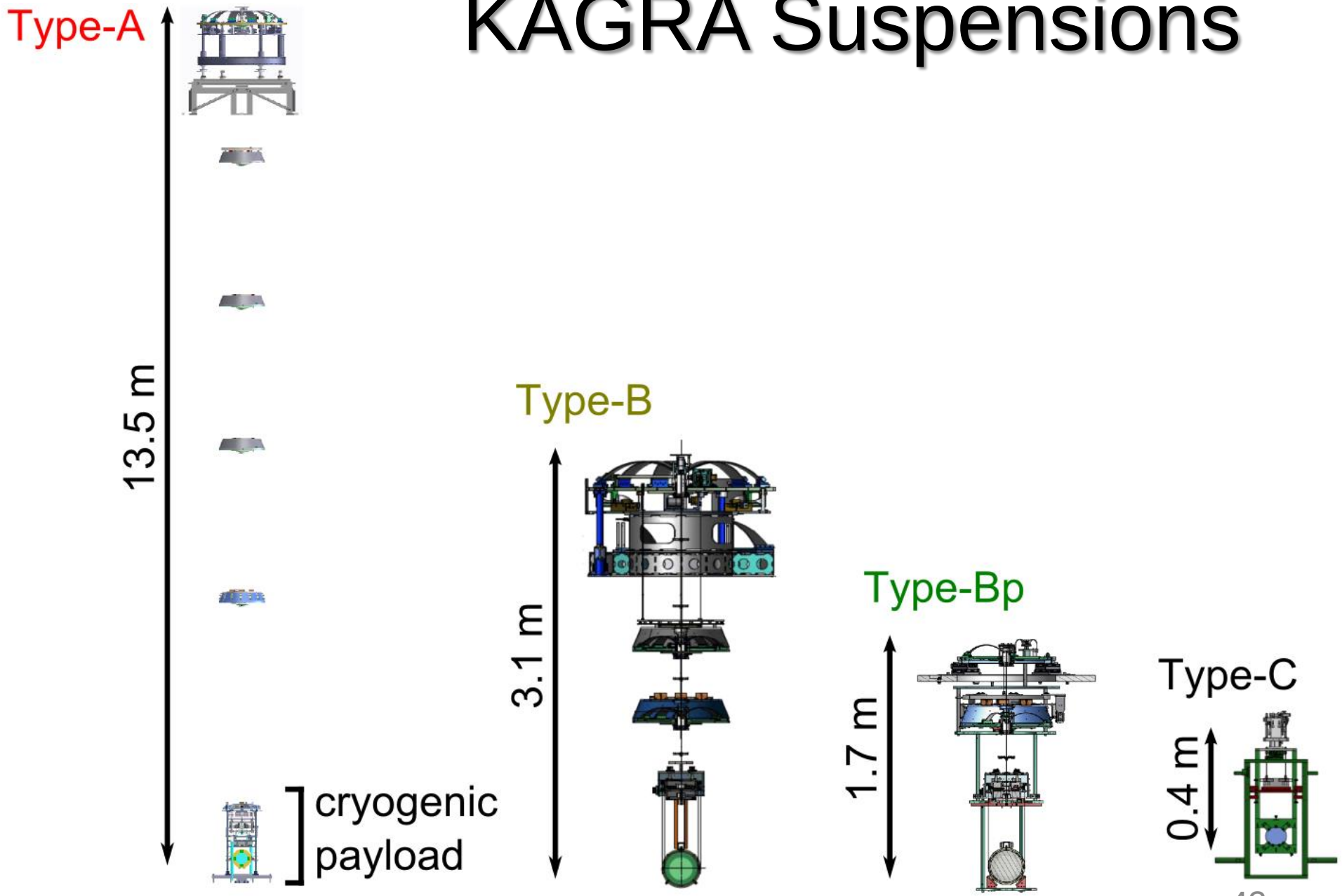
TM suspended by 4 sapphire fibers
(35 cm long, 1.6 mm dia.)
RM suspended by 4 CuBe fibers

KAGRA Cryostat Schematic

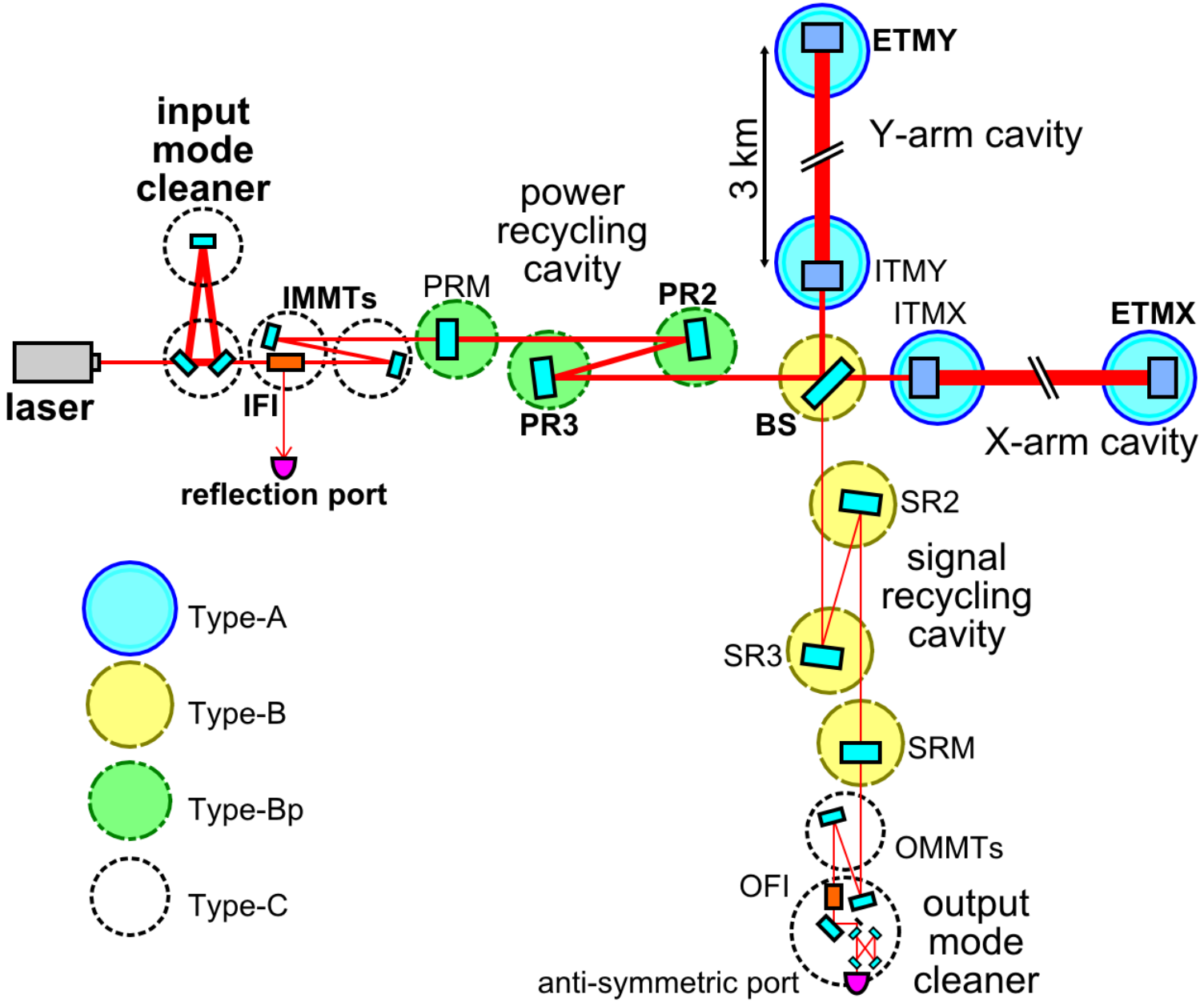




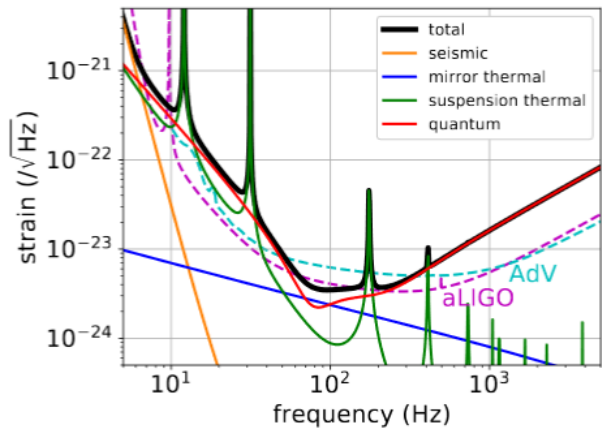
KAGRA Suspensions



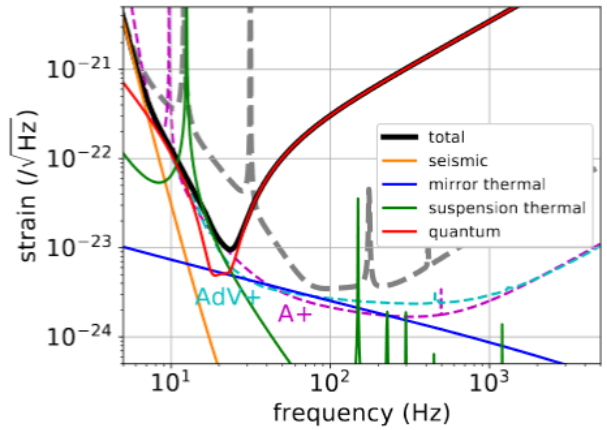
KAGRA Interferometer



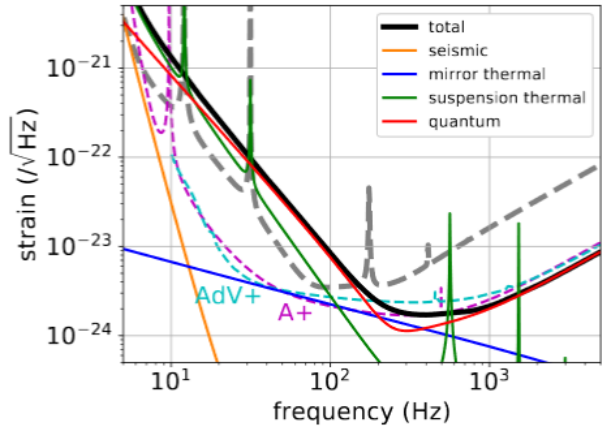
Possible KAGRA Upgrade Plans



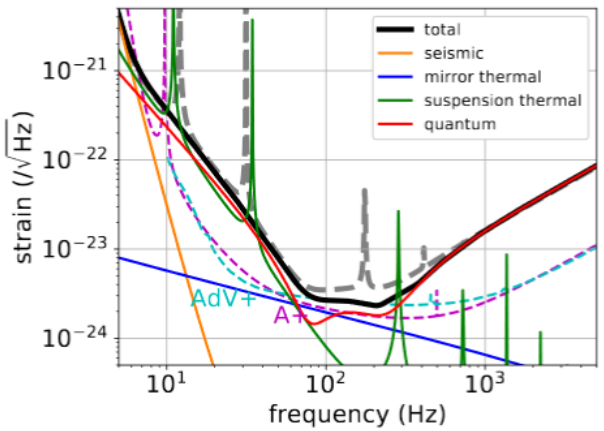
(a) bKAGRA



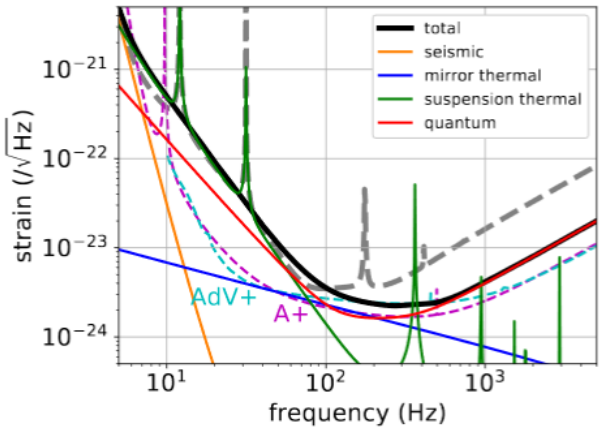
(b) LF



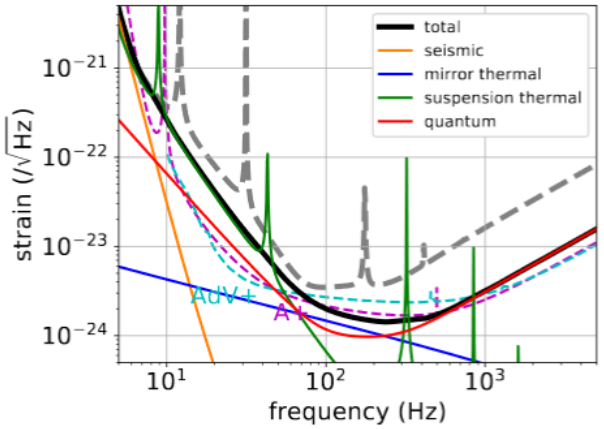
(c) HF



(d) 40kg



(e) FDSQZ



(f) Combined

Y. Michimura+,
PRD 97, 122003 (2018);
JGW-T1809537

Possible KAGRA Upgrade Plans

Y. Michimura+,
PRD 97, 122003 (2018);
JGW-T1809537

		bKAGRA	LF	HF	40kg	FDSQZ	Combined
detuning angle (deg)	$\phi_{\rm det}$	3.5	28.5	0.1	3.5	0.2	0.3
homodyne angle (deg)	ζ	135.1	133.6	97.1	123.2	93.1	93.0
mirror temperature (K)	$T_{\rm m}$	22	23.6	20.8	21.0	21.3	20.0
SRM reflectivity (%)	$R_{\rm SRM}$	84.6	95.5	90.7	92.2	83.2	80.9
fiber length (cm)	$l_{\rm f}$	35.0	99.8	20.1	28.6	23.0	33.1
fiber diameter (mm)	$d_{\rm f}$	1.6	0.45	2.5	2.2	1.9	3.6
mirror mass (kg)	m	22.8	22.8	22.8	40	22.8	100
input power at BS (W)	I_0	673	4.5	3440	1500	1500	3470
maximum detected squeezing (dB)		0	0	6.1	0	5.2 (FC)	5.1 (FC)
$100M_\odot$-$100M_\odot$ inspiral range (Mpc)		353	**2099**	114	412	318	702
$30M_\odot$-$30M_\odot$ inspiral range (Mpc)		1095	1094	271	1269	855	1762
$1.4M_\odot$-$1.4M_\odot$ inspiral range (Mpc)		**153**	85	156	**202**	**179**	**307**
median sky localization error (deg^2)		0.183	0.507	**0.105**	0.156	0.119	0.099