Main Interferometer Configuration for Early Phase of bKAGRA

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Situation

- Spare ETMs have large and asymmetric loss and absorption (JGW-T1707281)
  - ETMX: 60ppm scattering, 200ppm coating absorption
  - ETMY: 287ppm scattering, (41ppm coating absorption)
    - ETMY values are from coating sample

- CRY group suggests to do some operation with spare ETMs before swapping (ETM swap in FY2019)

- MIF group suggests to change SRM reflectivity to make KAGRA compatible with GW detection as soon as possible (JGW-G1707078)

- Many people want to seek into the possibility of joining O3

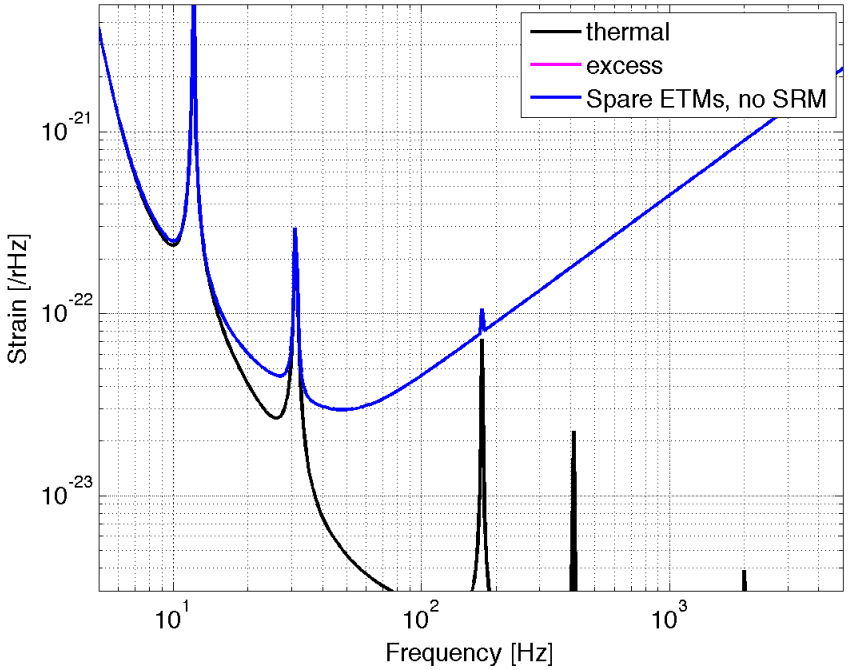
Sensitivity Calculations

- Case 1: PRFPMI with spare ETMs
  - assumed that both ETMs are spare ones
  - input power is set to 4 W (8 W at BS)
    (maximum power considering absorption of ETM)
- Case 2: PRFPMI with final ETMs
  - input power is set to 10 W (100 W at BS)
- Case 3: RSE with final ETMs
  - input power is set to 10 W (100 W at BS)
  - done with different SRM reflectivity

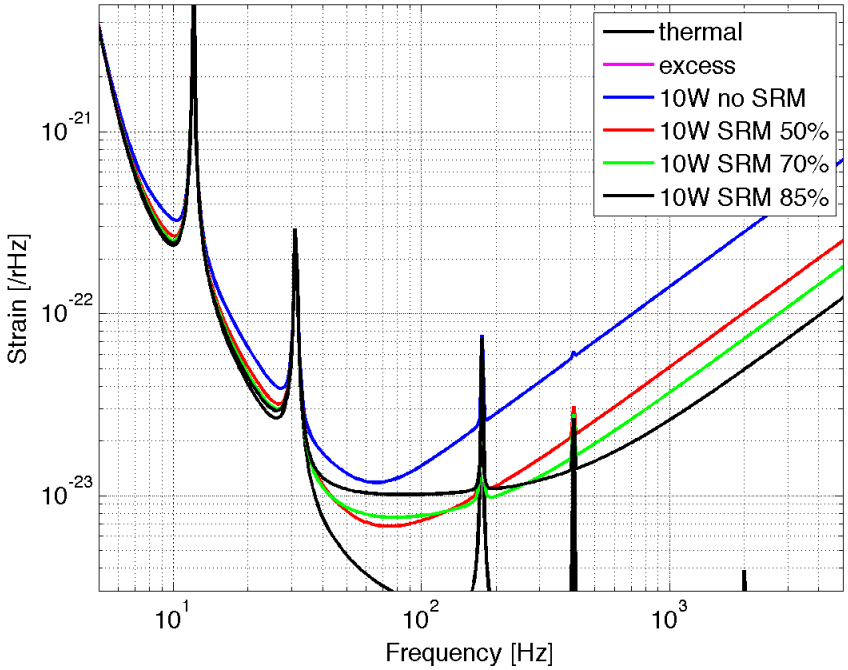
- Calculations were done for different excess noise
- Shot noise coupling is included
- Done by Yutaro Enomoto

Sensitivity with No Excess noise

Spare PRFPMI



Final PRFPMI / Final RSE



Spare PRFPMI
BNS1.4: 31 Mpc
BBH30: 0.42 Gpc
BBH event: 2.5 /yr

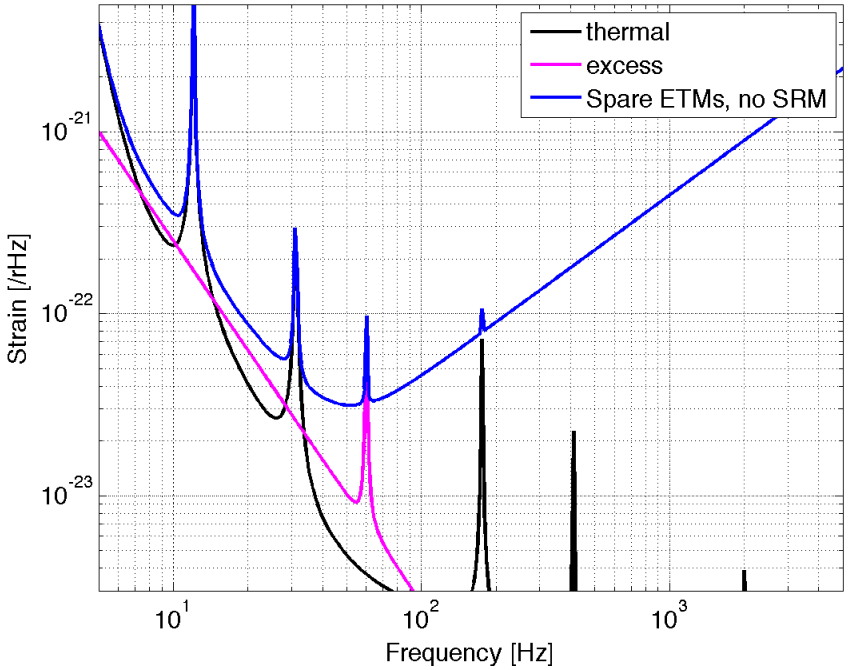
Final PRFPMI
BNS1.4: 58 Mpc
BBH30: 0.82 Gpc
BBH event: 20 /yr

Final RSE (SRM 70%)
BNS1.4: 93 Mpc
BBH30: 1.4 Gpc
BBH event: 103 /yr

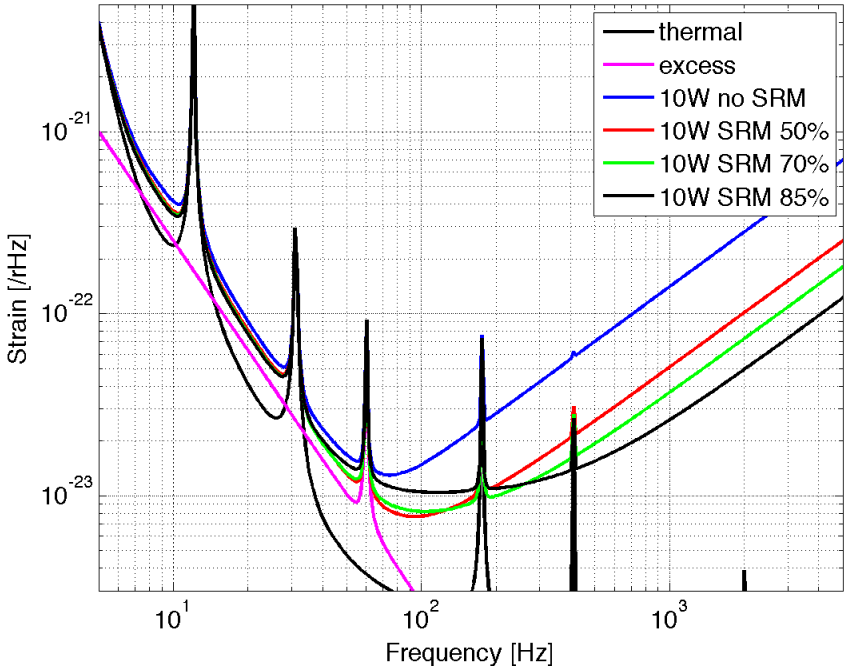
Event rate based on current best estimate (average), SNR=8

Sensitivity with O1 Excess noise

Spare PRFPMI



Final PRFPMI / Final RSE



Spare PRFPMI
BNS1.4: 27 Mpc
BBH30: 0.35 Gpc
BBH event: 1.5 /yr

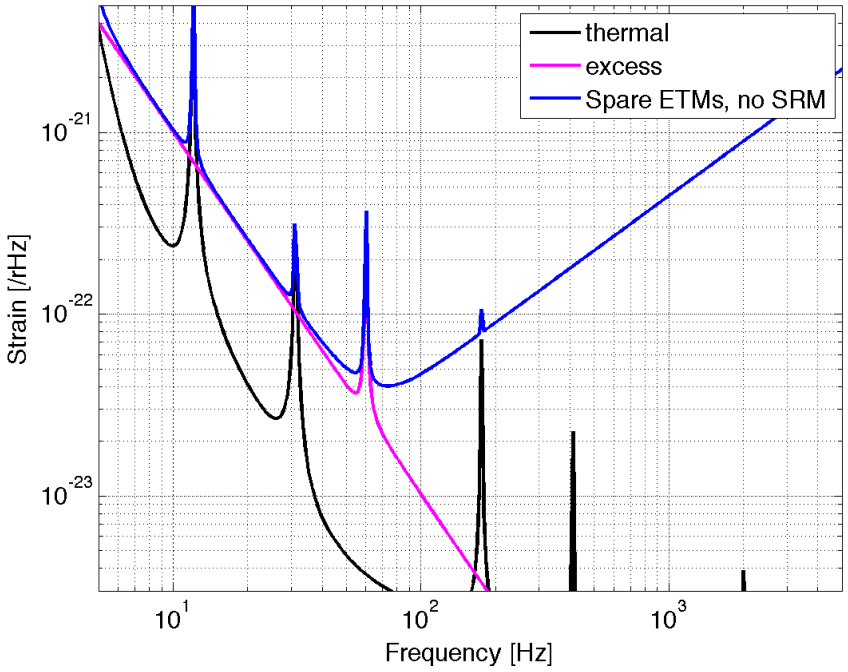
Final PRFPMI
BNS1.4: 48 Mpc
BBH30: 0.66 Gpc
BBH event: 10 /yr

Final RSE (SRM 70%)
BNS1.4: 71 Mpc
BBH30: 1.1 Gpc
BBH event: 44 /yr

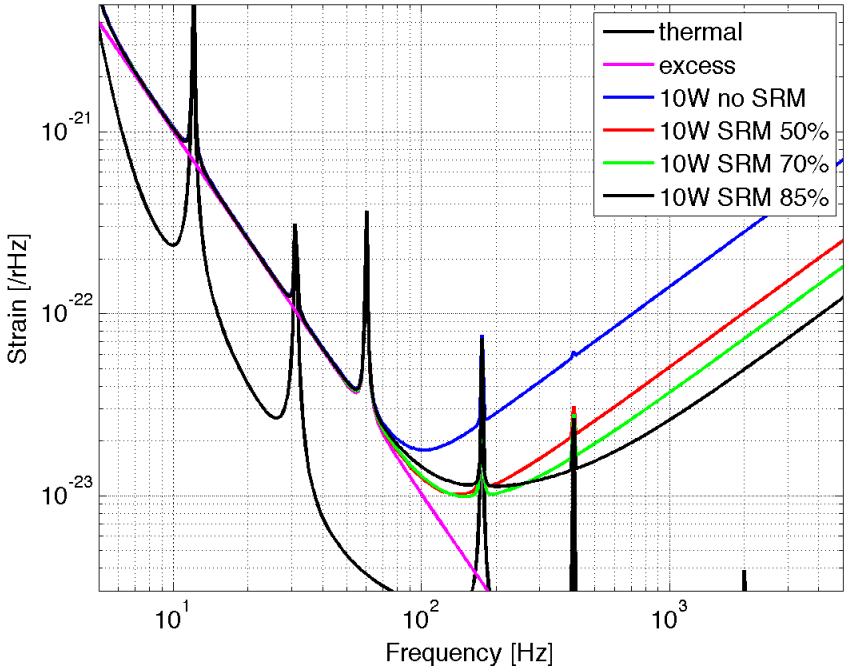
Event rate based on current best estimate (average), SNR=8

Sensitivity with x4 O1 Excess noise

Spare PRFPMI



Final PRFPMI / Final RSE



Spare PRFPMI
BNS1.4: 16 Mpc
BBH30: 0.21 Gpc
BBH event: 0.3 /yr

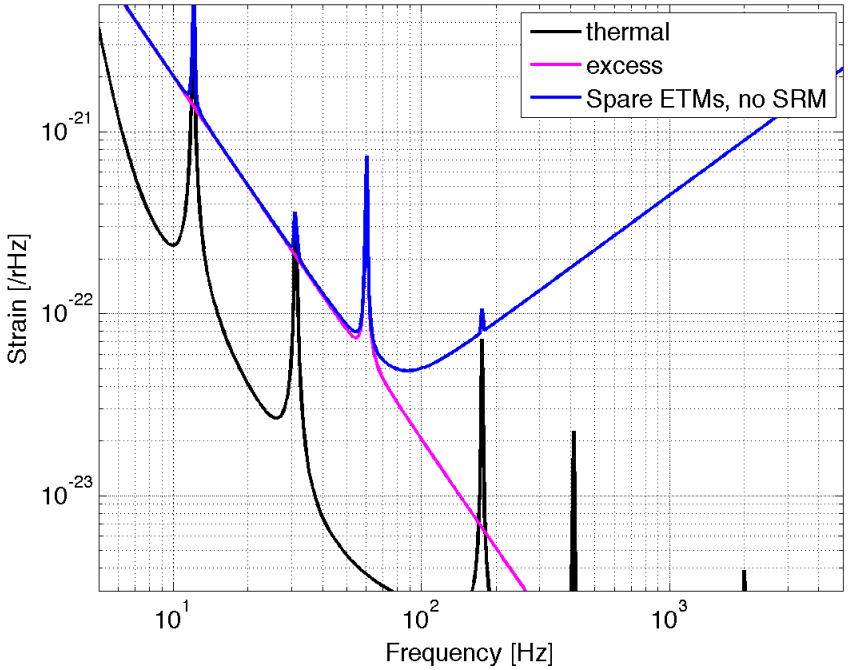
Final PRFPMI
BNS1.4: 27 Mpc
BBH30: 0.37 Gpc
BBH event: 1.8 /yr

Final RSE (SRM 70%)
BNS1.4: 42 Mpc
BBH30: 0.62 Gpc
BBH event: 7.7 /yr

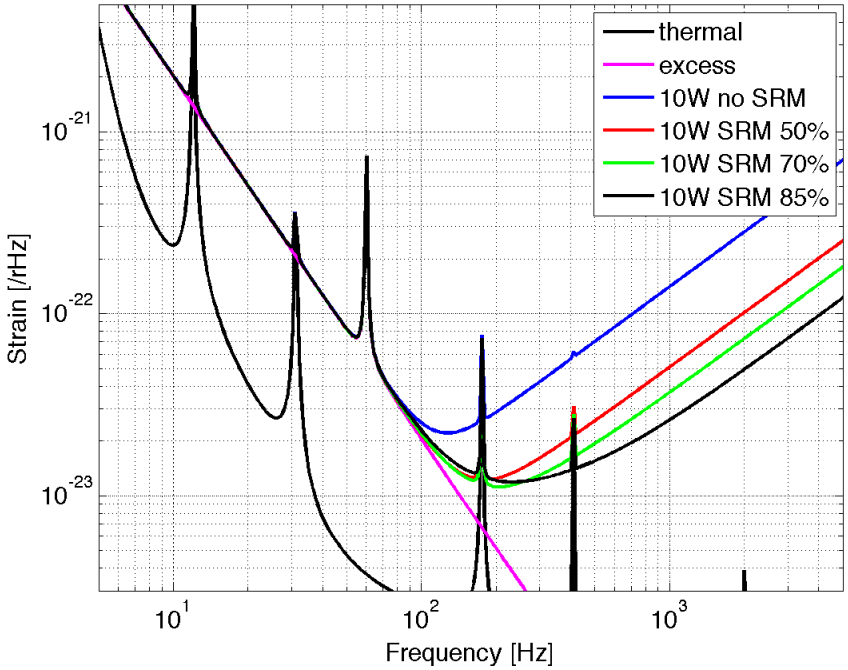
Event rate based on current best estimate (average), SNR=8

Sensitivity with x8 O1 Excess noise

Spare PRFPMI



Final PRFPMI / Final RSE



Spare PRFPMI
BNS1.4: 11 Mpc
BBH30: 0.15 Gpc
BBH event: 0.1 /yr

Final PRFPMI
BNS1.4: 19 Mpc
BBH30: 0.26 Gpc
BBH event: 0.6 /yr

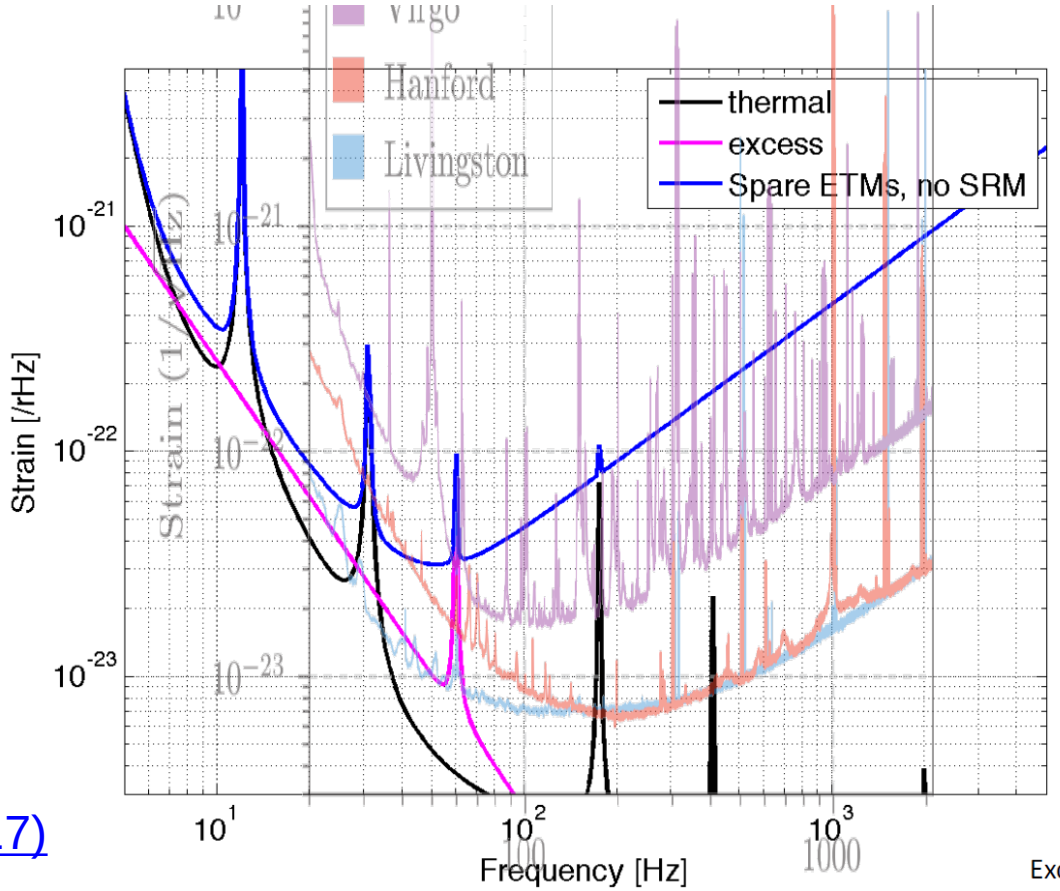
Final RSE (SRM 70%)
BNS1.4: 30 Mpc
BBH30: 0.45 Gpc
BBH event: 2.9 /yr

Event rate based on current best estimate (average), SNR=8

Comparison with AdV and aLIGO

- Excess noise of O1 x4 is roughly Advanced Virgo O2 level noise at low frequency
- KAGRA (especially PRFPMI case) relies on low frequency sensitivity to gain inspiral range

- Excess noise will be critical in PRFPMI case



PRL **119**, 141101 (2017)

Excess: 1

Summary on Sensitivity

- Spare PRFPMI gives only 2.5 event/year with best sensitivity (without any excess noise, maximum power)
- Swapping ETMs gives roughly x2 the inspiral range
- RSE further gives roughly x1.5 the inspiral range

- To achieve AdV O2 level sensitivity, excess noise have to be roughly
  - Spare PRFPMI: smaller than aLIGO O1 level
  - Final PRFPMI: smaller than x4 aLIGO O1 level
  - Final RSE: smaller than x8 aLIGO O1 level
- There is a trade-off between how much installation work necessary before O3 and how much noise hunting necessary

Risks with Spare PRFPMI

- ETMY absorption is measured with only 2-inch sample and we don't know real abosorption
- Considering ETM absorption of 200ppm and ~0.8W cooling capability, power at BS is 8 W at maximum
  (ETM temperature will be 23.1 K)
- Considering ETM loss of 200ppm, arm cavity reflectivity is only ~80 % (c.f. PRM reflectivity is 90 %)
- Power recycling gain will be ~2 (instead of 10)
- Arm asymmetry is also unknown, and laser intensity/frequency noise could harm the sensitivity
  - CMRR could be much worse
  * Even if loss asymmetry is 200ppm / 500ppm, contrast is $4r_X r_Y/(r_X^2+r_Y^2)$=99%, so it is OK
- Alignment sensing and control could be awful

Strategies for First Operation

- Case 1: PRFPMI with spare ETMs
  - Swap ETMs after PRFPMI operation
- Case 2: PRFPMI with final ETMs
  - Swap ETMs before PRFPMI operation
- Case 3: RSE with final ETMs
  - Swap ETMs before PRFPMI operation
  - We could use different SRM reflectivity

- For each cases, usual schedule is estimated and accelerated schedule to join O3 is proposed
  - Joining O3 is not possible in either cases with current estimate of schedule
  - acceleration of installation work and commissioning necessary

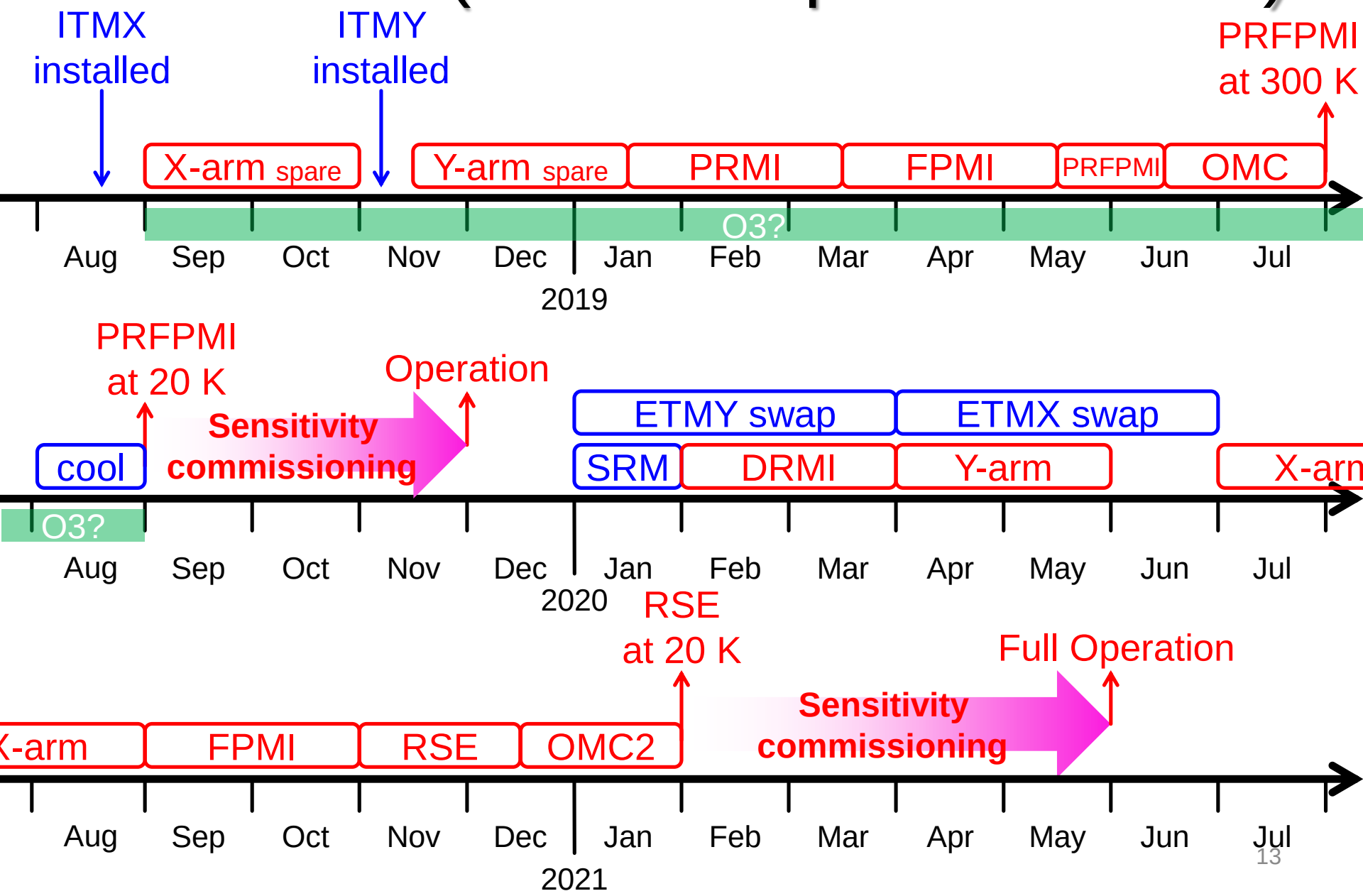
Some Details on Scheduling

- Installation Schedule
  2017.9 BS and PRs ready
  2017.11 spare ETMs ready
  By 2018.3 bKAGRA Phase 1 complete, ETMs cooled down
  2018.7 Green ready
  2018.9 ITMX ready (Y first?)
  2018.9 SRs ready
  2018.11 ITMY ready

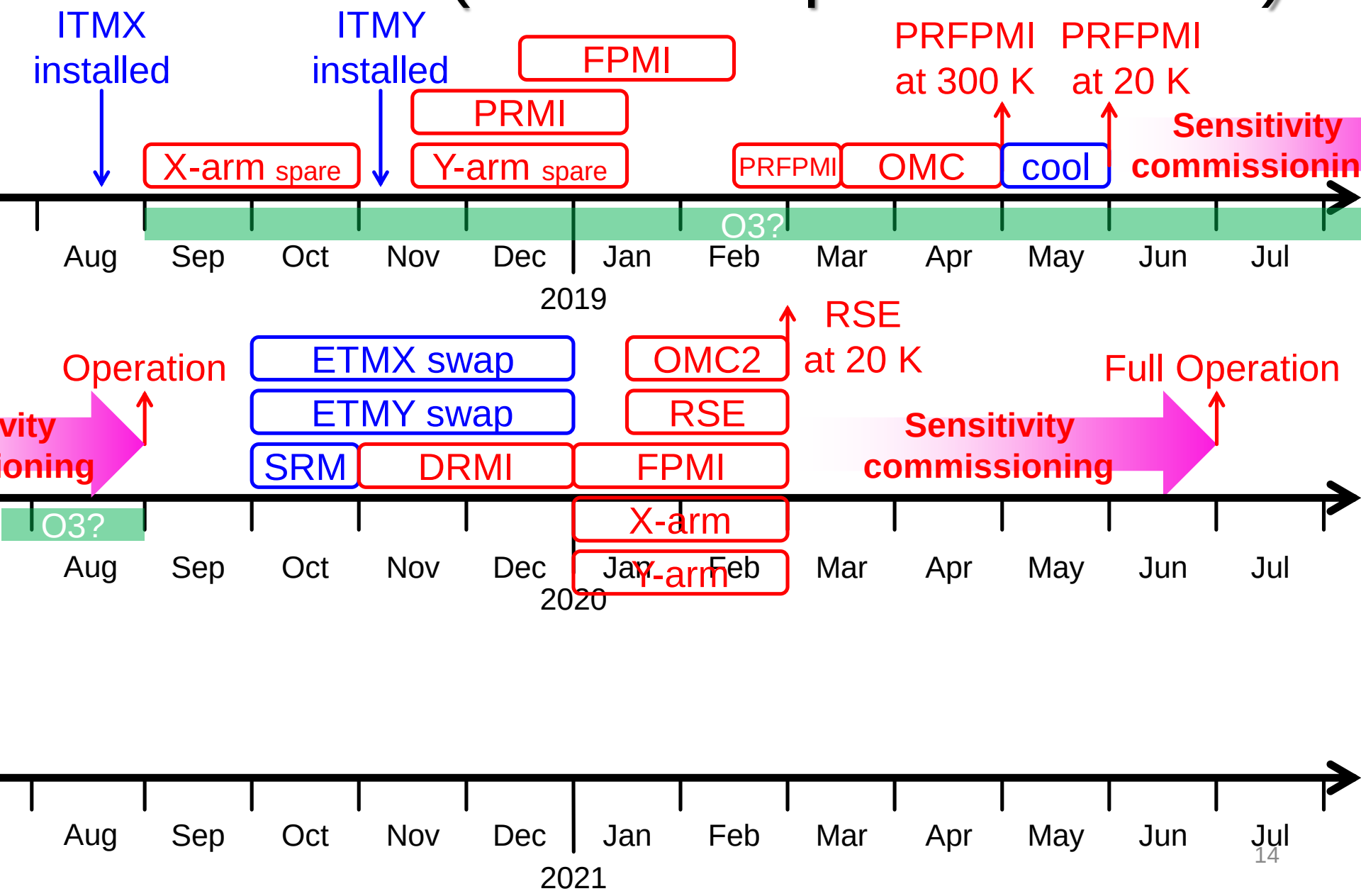
  * ETM swap takes 2.5 months (assumed we have to swap both)
  * Cooling down takes 1 month
  * PRFPMI operation will delay SRM installation

- Commissioning Estimate (based on aLIGO/AdV experience) JGW-T1707079
  X arm: 2 months
  Y arm: 2 months
  FPMI: 2 months
  DRMI: 2 months (PRMI: 2 months)
  RSE: 1.5 months (PRFPMI: 1 month)
  OMC: 1.5 months
  Stable lock to observation: 7 months for RSE, 3 months for PRFPMI

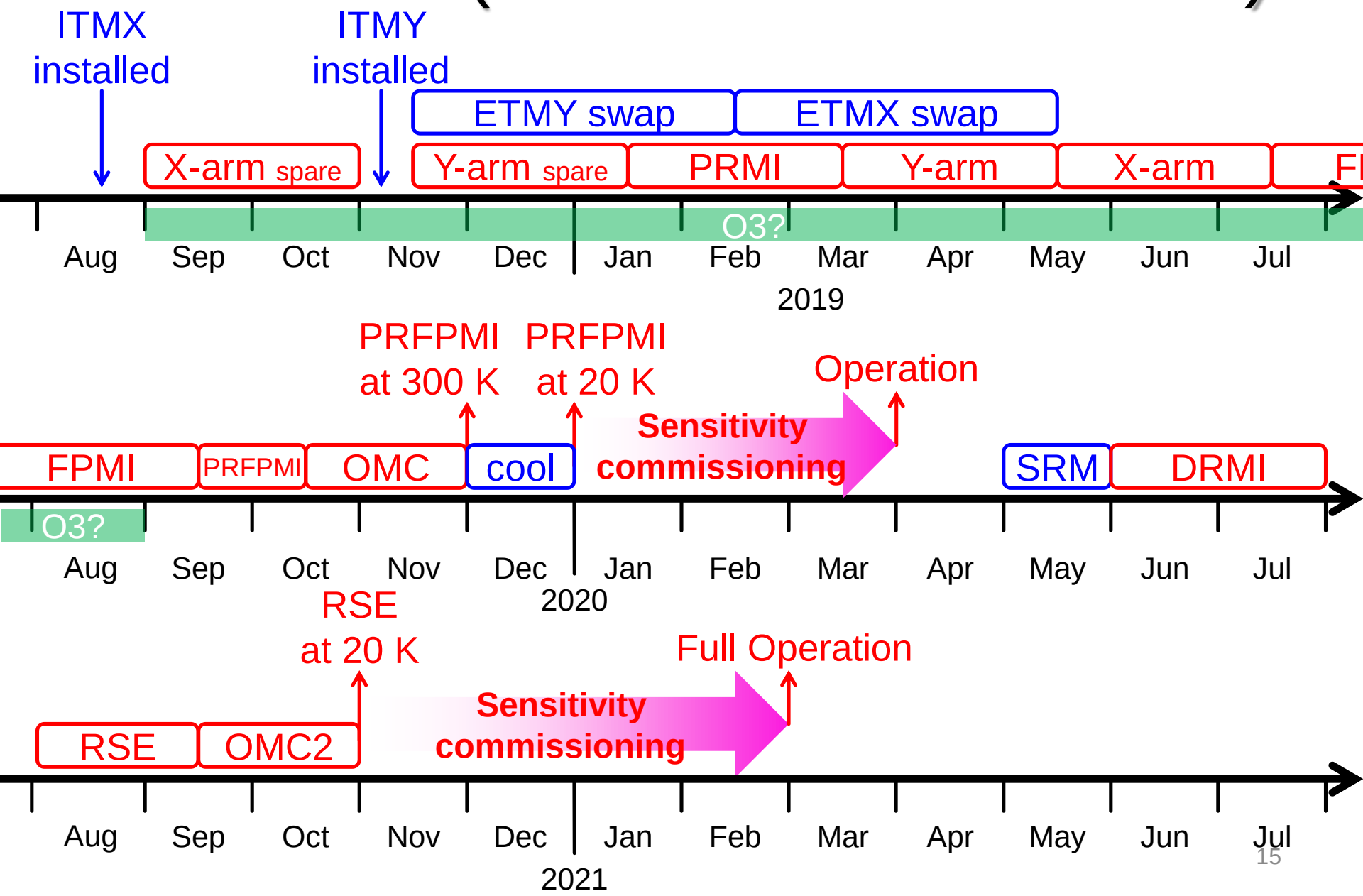
Schedule (Case 1: Spare PRFPMI)



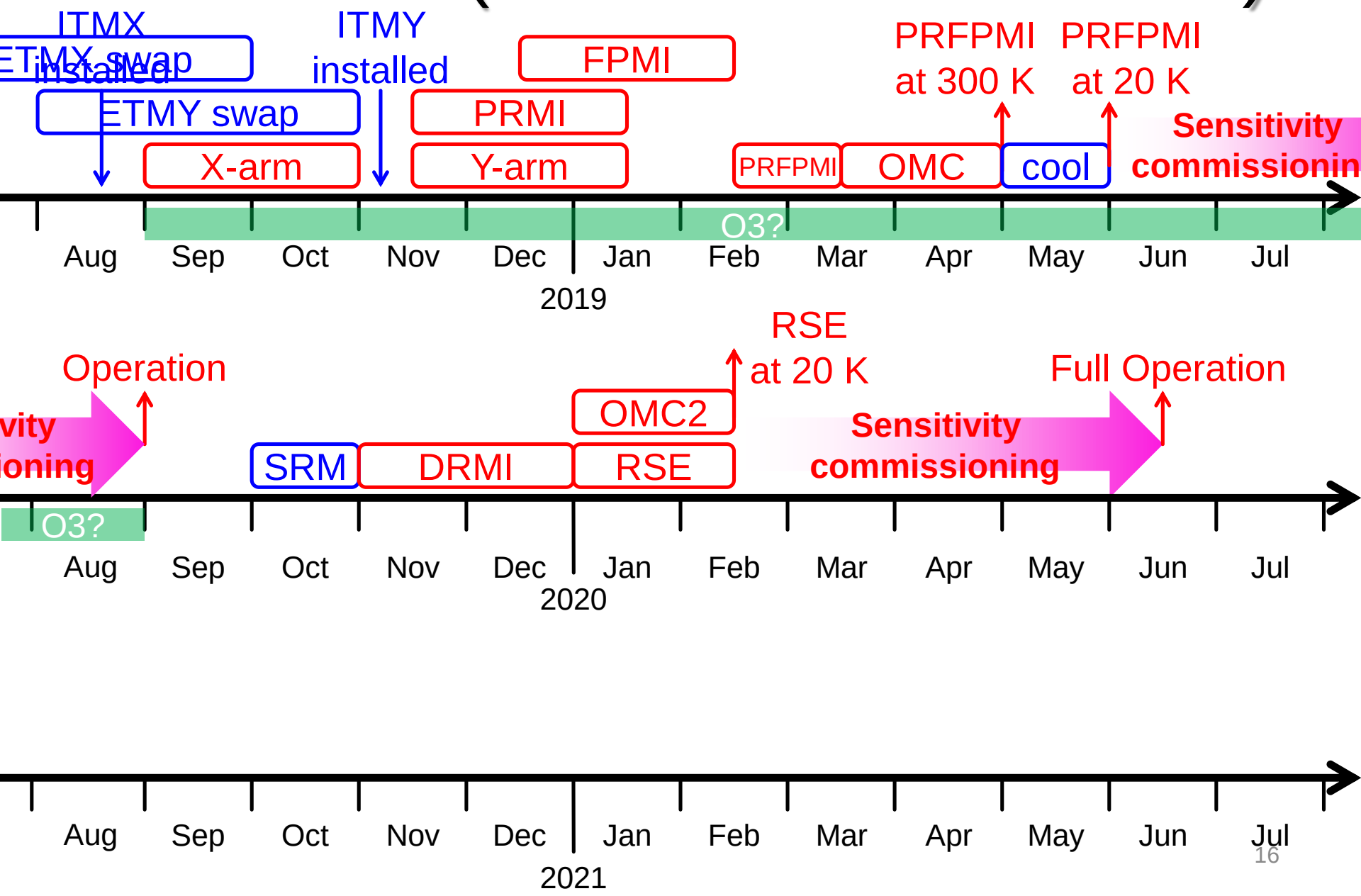
Accelerated Schedule (Case 1: Spare PRFPMI)



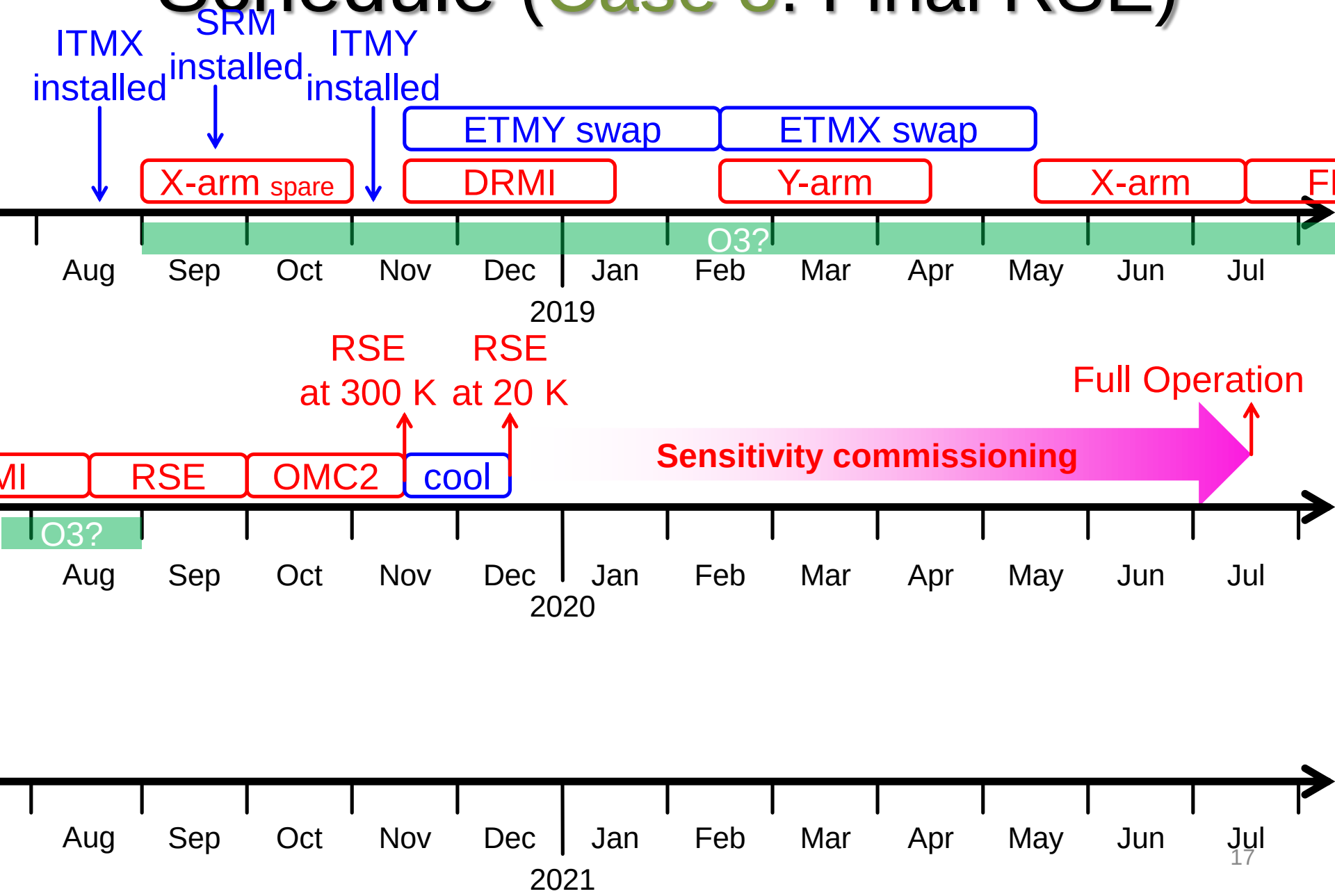
Schedule (Case 2: Final PRFPMI)



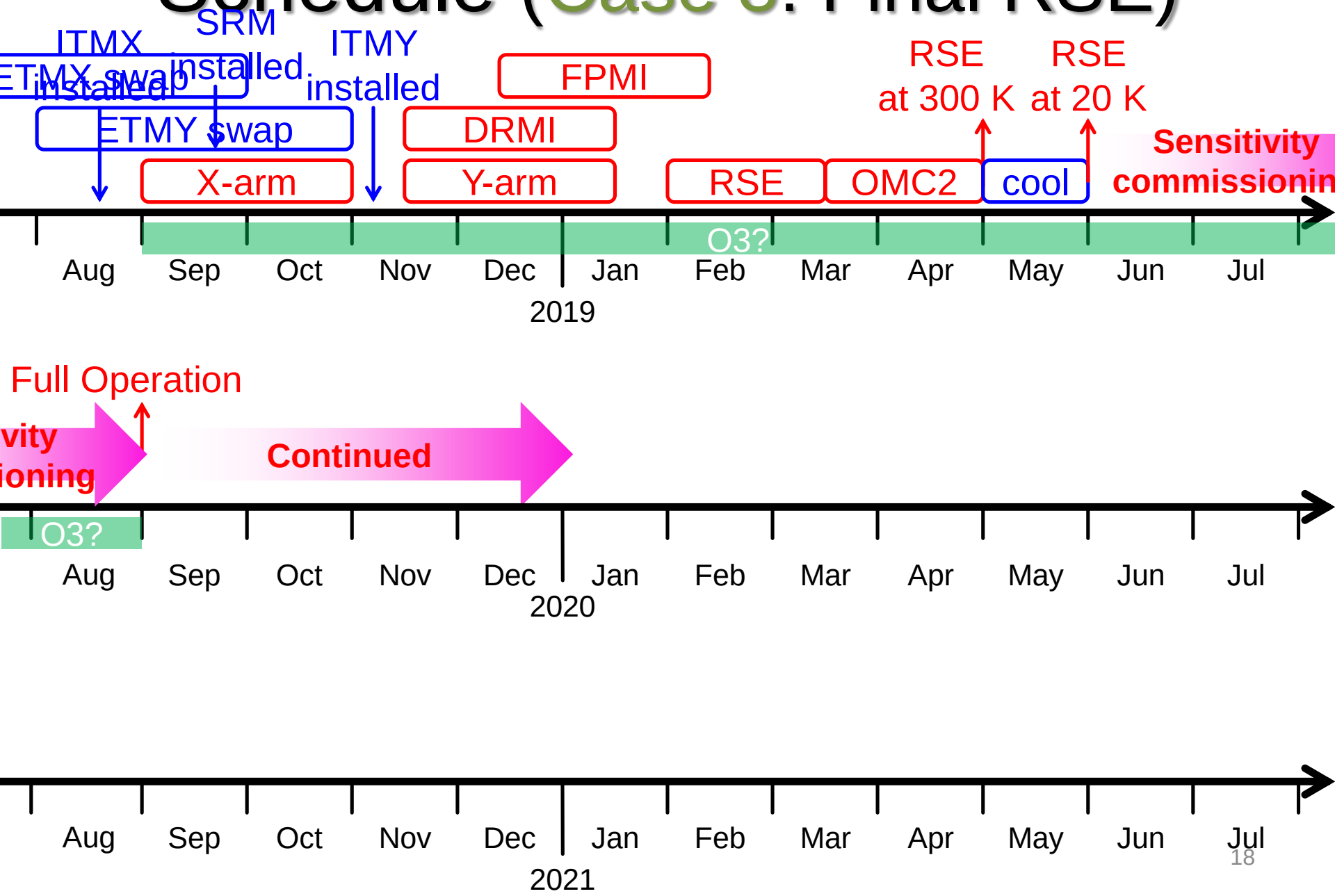
Accelerated Schedule (Case 2: Final PRFPMI)



Schedule (Case 3: Final RSE)



Accelerated Schedule (Case 3: Final RSE)



Summary

	Case 1 Spare PRFPMI	Case 2 Final PRFPMI	Case 3 Final RSE
Installation before O3	No extra work	ETM swap	ETM swap, SRM
Installation after O3	ETM swap, SRM	SRM	None
Commissioning with spare ETM	Upto PRFPMI	Upto both arm (none if acceralated)	Upto single arm (none if acceralated)
Green locking	Not necessary	Not necessary	Necessary
Sensitivity with O1 excess noise	27 Mpc (with max input)	48 Mpc (with 10 W input)	71 Mpc (with 10 W input)
Tolerable excess noise to achieve AdV O2 sens.	~ O1 level	~ x4 O1 level (~ AdV O2 level)	~ x8 O1 level
Power limit	~8 W at BS	~670 W at BS	~670 W at BS

Our Suggestion

- Accelerated Case 3
- Swap ETMs to final ones as soon as possible to avoid unnecessary commissioning work, unexpected troubles and noises with lossy spare ETMs
- Install 2-inch SRM with doughnut metal mass as scheduled (by 2018.9) to add flexibility in the configuration
  - If we have some trouble with green locking or dual-recycling, we can remove 2-inch mirror to do PRFPMI (switch to Case 2).
  - This decision can be made during first phase of O3 (~end of 2018) at latest
- Spare PRFPMI depends on luck (low excess noise, no unexpected issue with lossy ETM), Final RSE depends on installation work. Latter seems more controllable.

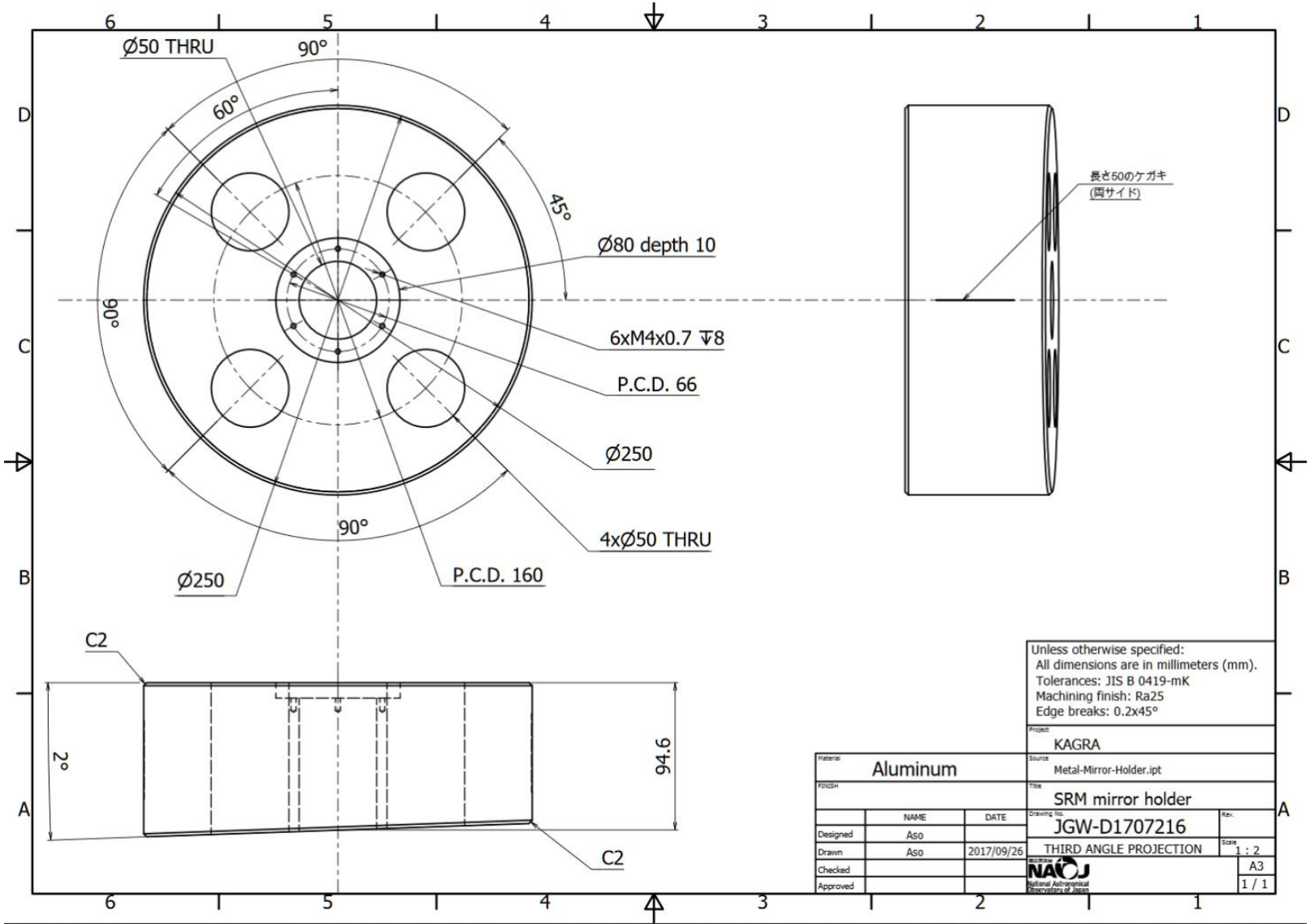
SRM with Different Reflectivity

- Metal mass design: almost completed by Aso
  ~15man-yen, 2-2.5 months
  (+ ~50man-yen with black coating?)
  → Does not delay SRM installation
- 2-inch SRM: estimate done by Hirose and Michimura
  ~100man-yen, 3-4 months
  → Does not delay SRM installation

- We are ready for 2-inch SRM with doughnut metal mass
- Adds more flexibility on interferometer configuration
  - PRFPMI is also possible with metal mass with no optic
  - installation/removal of 2-inch SRM is possible inside the vacuum chamber at anytime

Doughnut Metal Mass

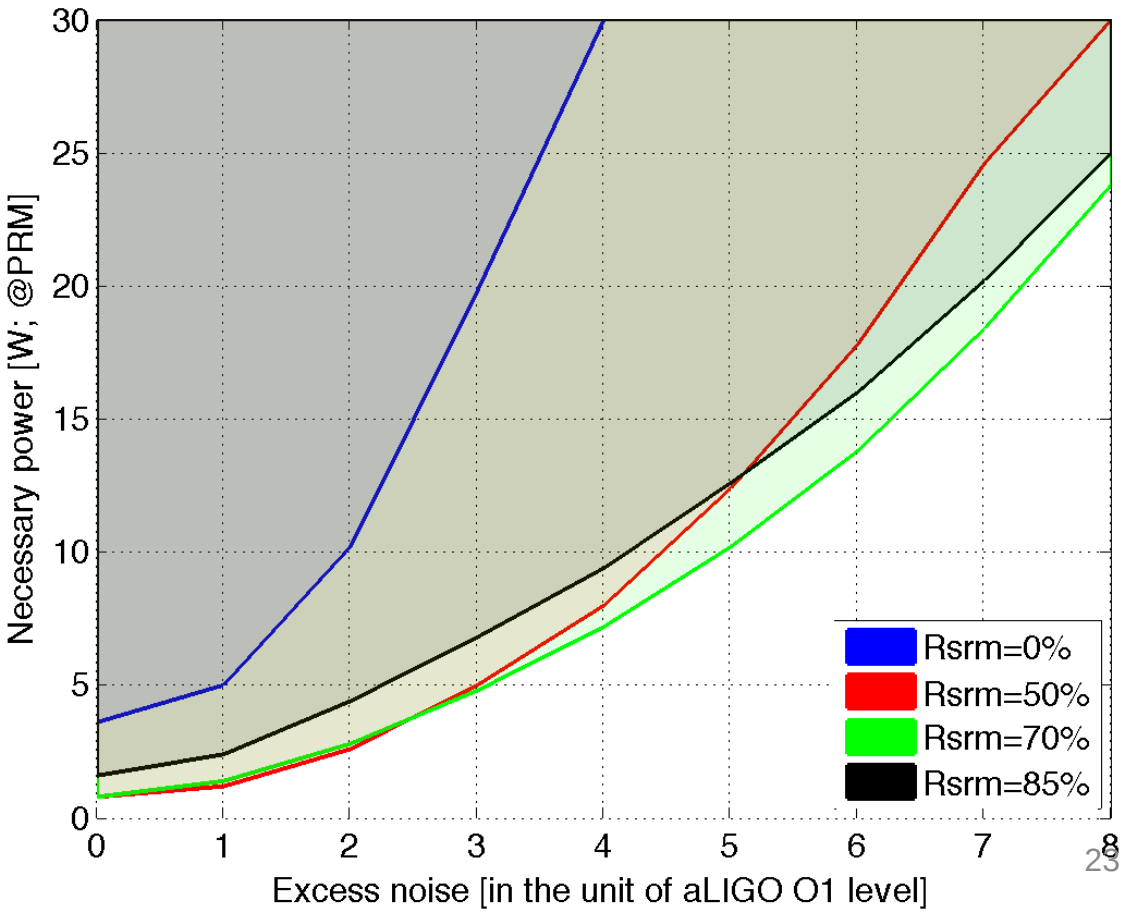
- Designed by Aso (see JGW-D1707216, JGW-D1707317)



Suggestion on SRM Reflectivity

- RSE with SRM reflectivity of 70% is strongest to excess noise at low power stage (see also, JGW-G1707078)

Input power necessary to reach
BNS1.4 : ~40 Mpc
BBH30: ~580 Mpc
BBH rate: ~ 6 /yr



MICH shot noise coupling included

Global Coordination

- If we are to join O3, we should coordinate with LV on data sharing and O3 period
- If we miss joining O3, we might have to operate as a single detector
- In either case, global coordination beforehand is a must

Related Issues

- If Final ETMX will be ready for Phase 1 in time, Final ETMX will be installed for Phase 1.
- WAB is not installed for Phase 1. To install WAB, we have to remove ETM. (JGW-G1706474)