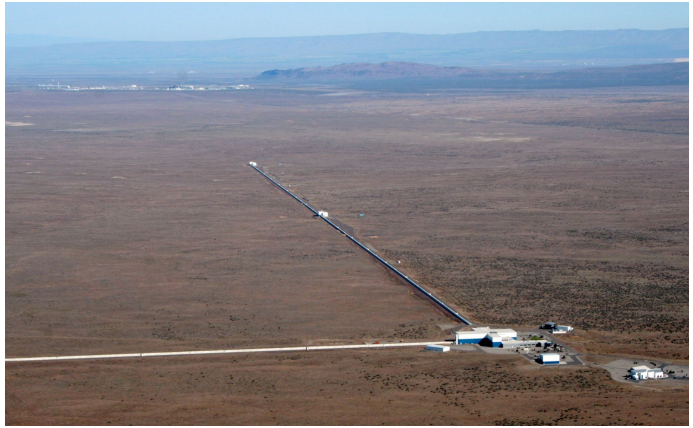
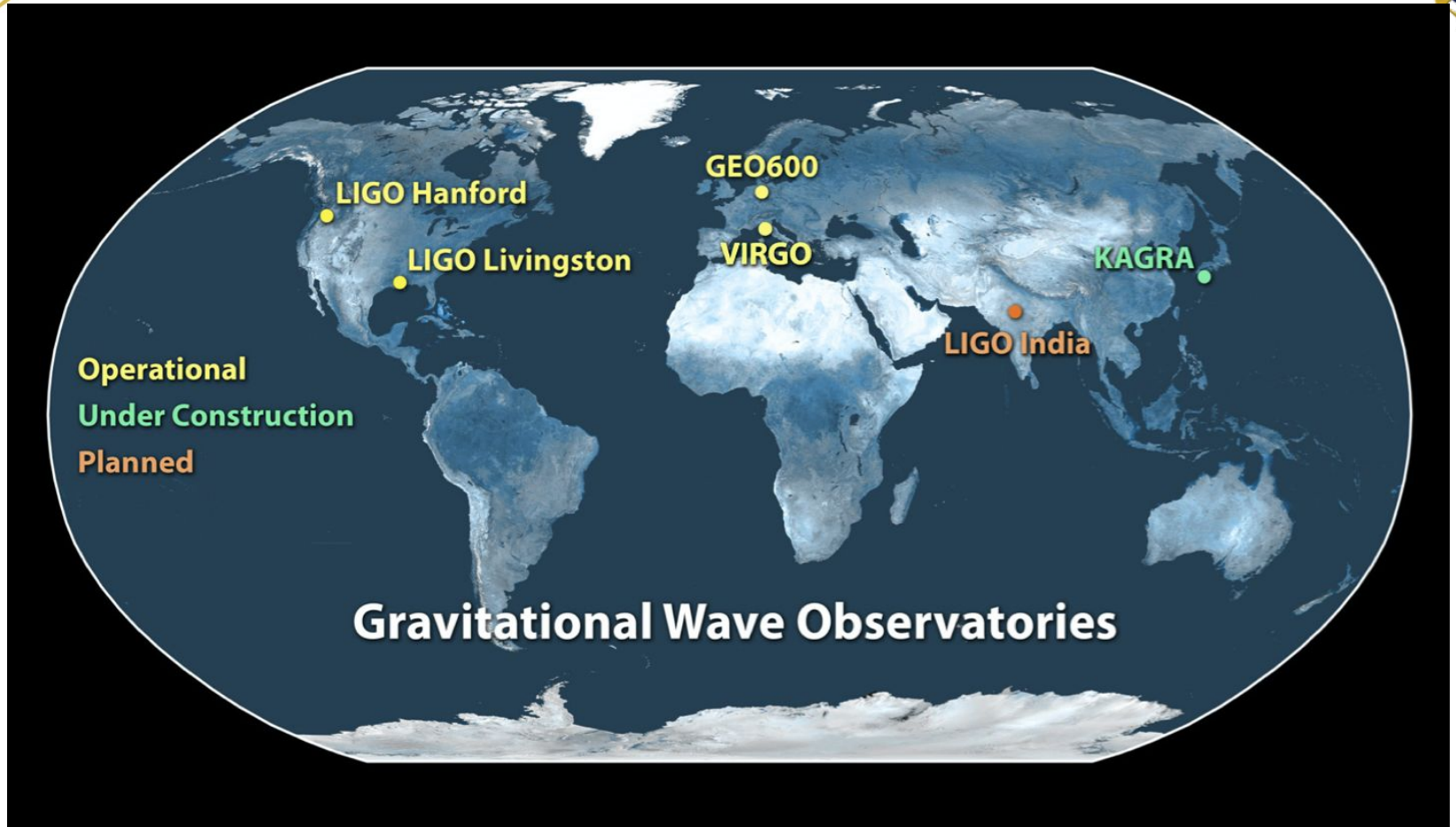
Overview of GW detection techniques with LIGO and Virgo, and their future plans



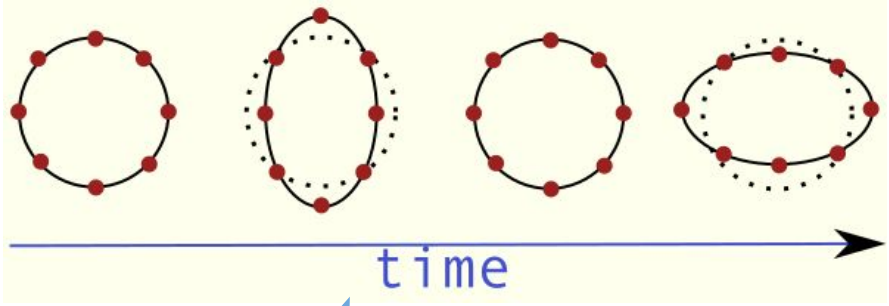
Anamaria Effler
Caltech
LIGO Livingston Observatory

Exploring the Dark Side of the Universe, 5th World Summit
June 4, 2024

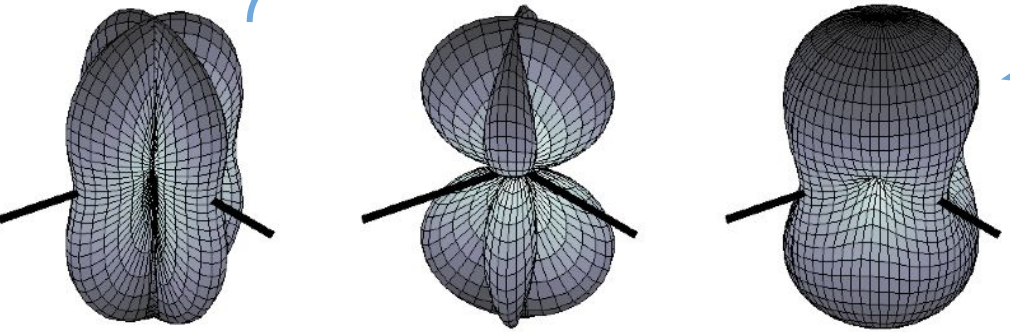
Map


LIGO Hanford
LIGO Livingston
GEO600
VIRGO
KAGRA
LIGO India
Operational
Under Construction
Planned
Gravitational Wave Observatories

How interferometers detect GW



+polarization



Antenna pattern not directional:
need network!

A gravitational wave manifests as a **differential arm signal** in an interferometer:
Strain = ΔL/L

Binary neutron star inspiral range (**BNS**): how far can we see two 1.4 solar mass neutron stars colliding, integrated over the average antenna pattern, with a signal-to-noise ratio of 8

How small: measure strain O(1e-22) or ~O(1e-19m) differential arm length

(same as measuring the distance from Earth to sun to a few atoms!)

Brief history

LIGO

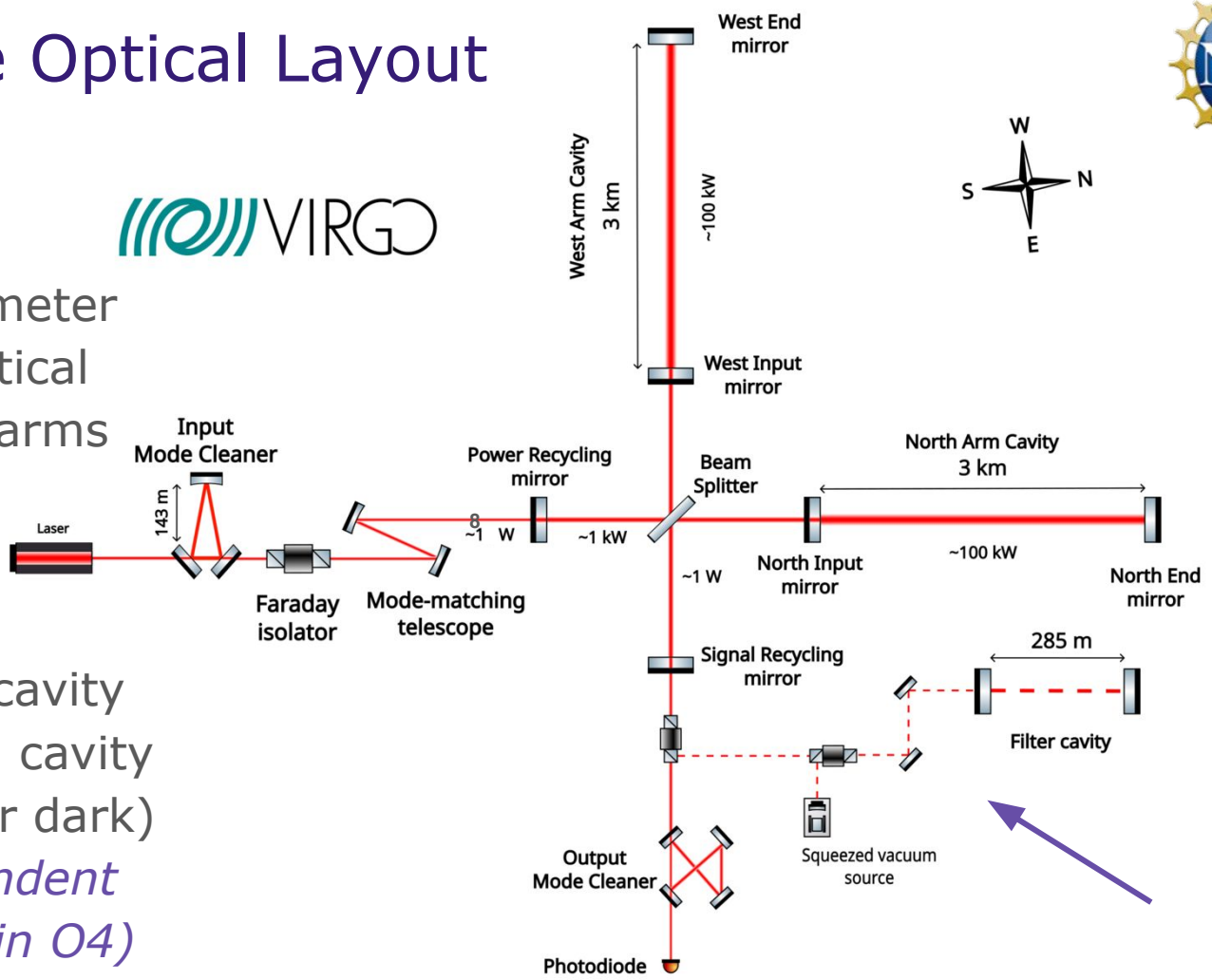
- First concept: R. Drever, K. Thorne, R. Weiss 1980's
- Funded by NSF 1992
- Construction finished circa 2000
- Initial LIGO era: 2002-2009
- Advanced LIGO: finished installation 2014
- First detection: Sep 14 2015

Virgo

- First concept: A.Giazotto, A Brillet 80's
- Funding CNFS, INFN 1993
- Completed 2003
- Initial Virgo era 2003-2011
- Joins advanced era observations 2017

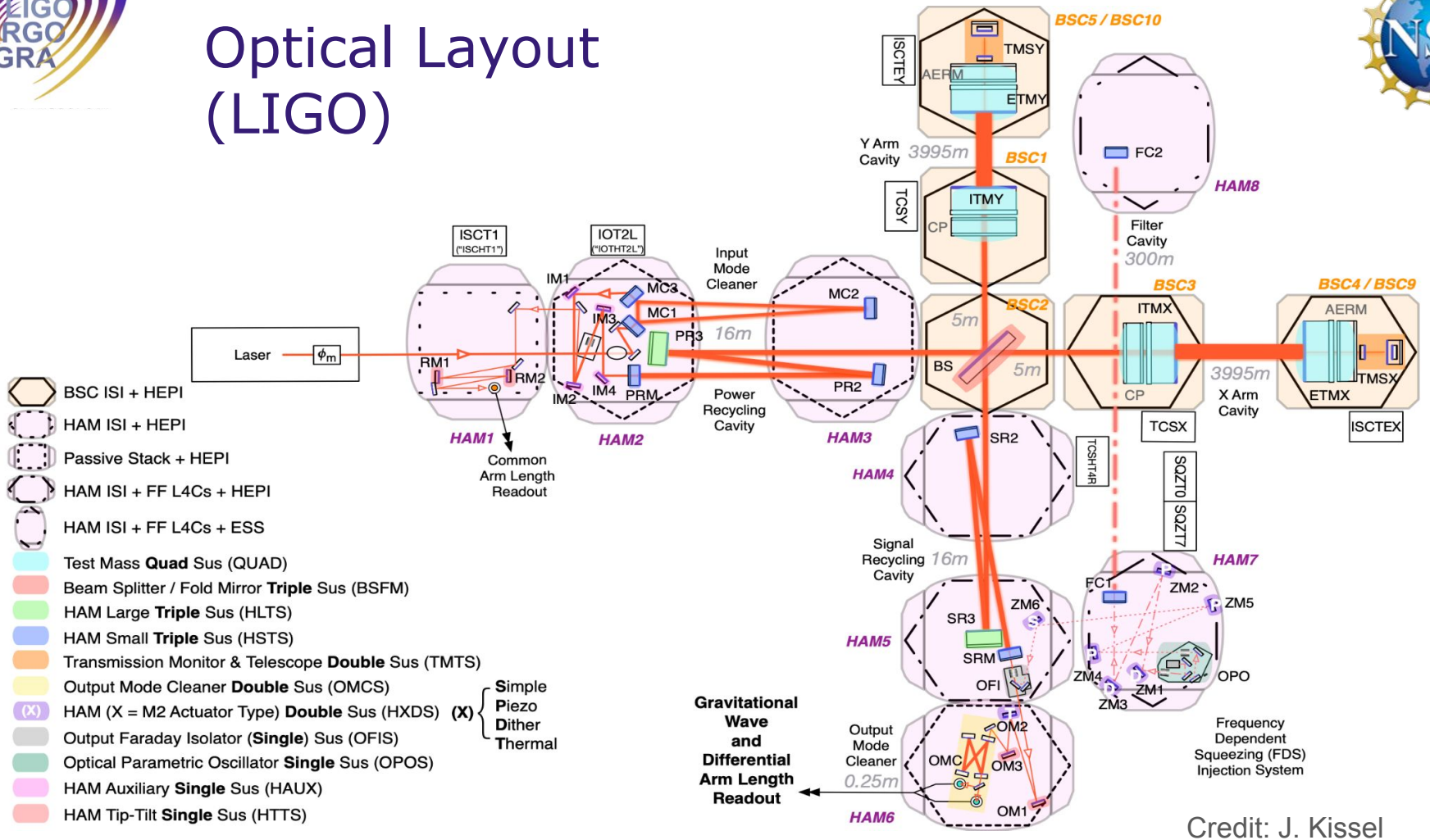
Simple Optical Layout

Michelson interferometer with Fabry-Perot optical cavities in the long arms



Power recycling cavity
Signal extraction cavity
DC readout (near dark)
Frequency-dependent squeezing (new in O4)

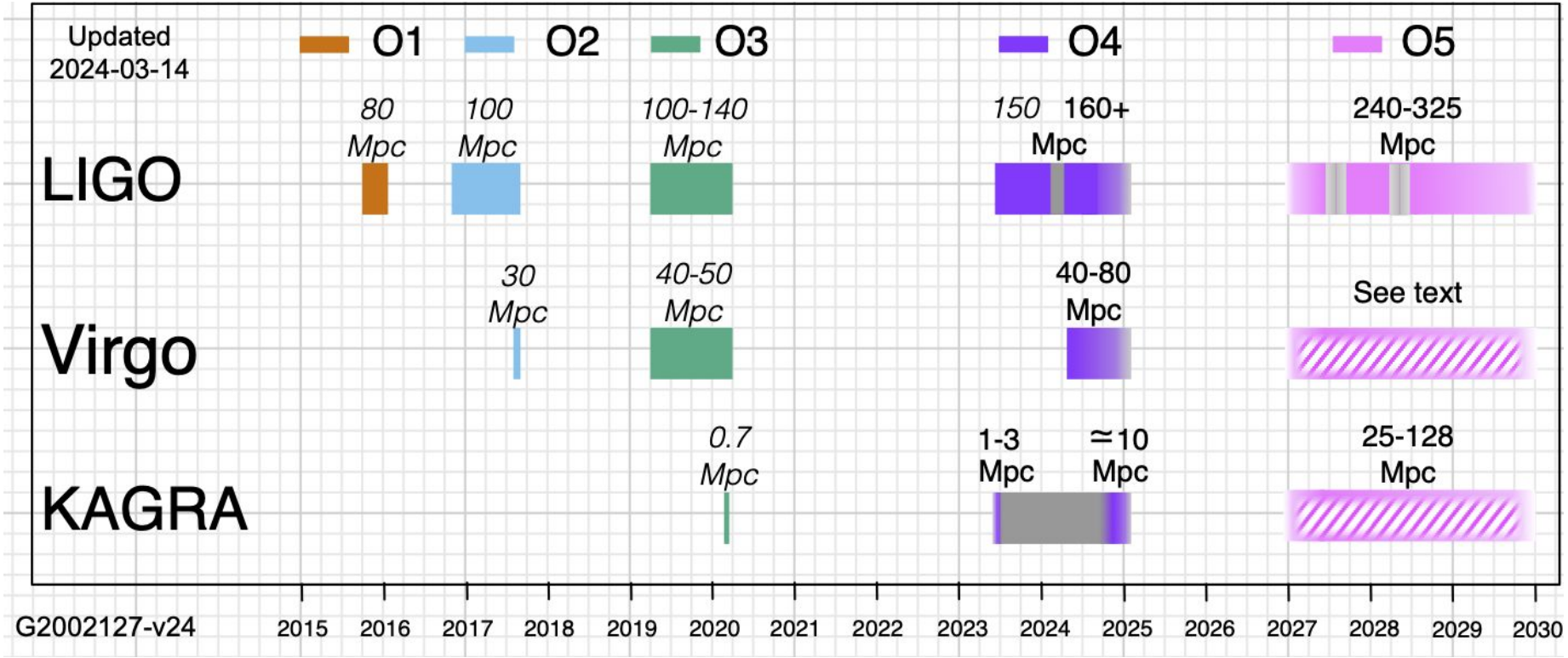
Optical Layout (LIGO)



Credit: J. Kissel

How detectors operate

we alternate periods of data taking (observing runs, O#) and periods of hardware upgrades



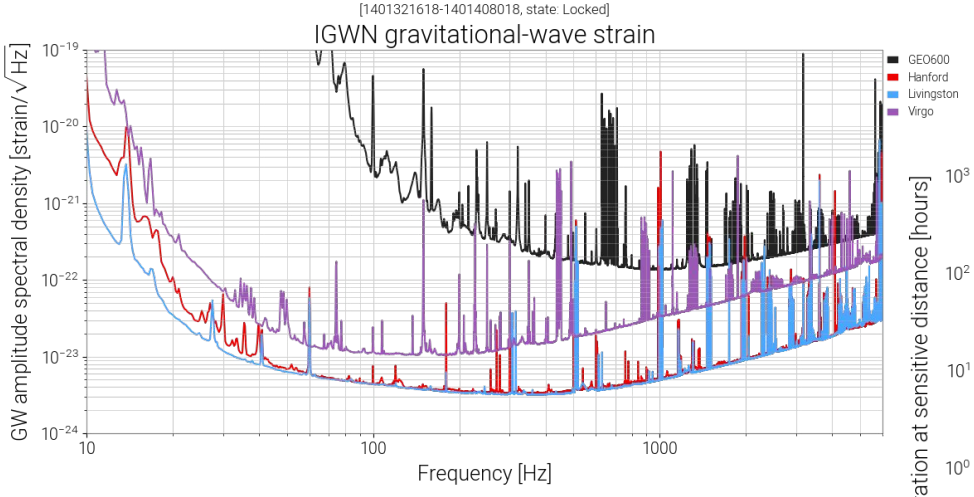
https://observing.docs.ligo.org/plan/

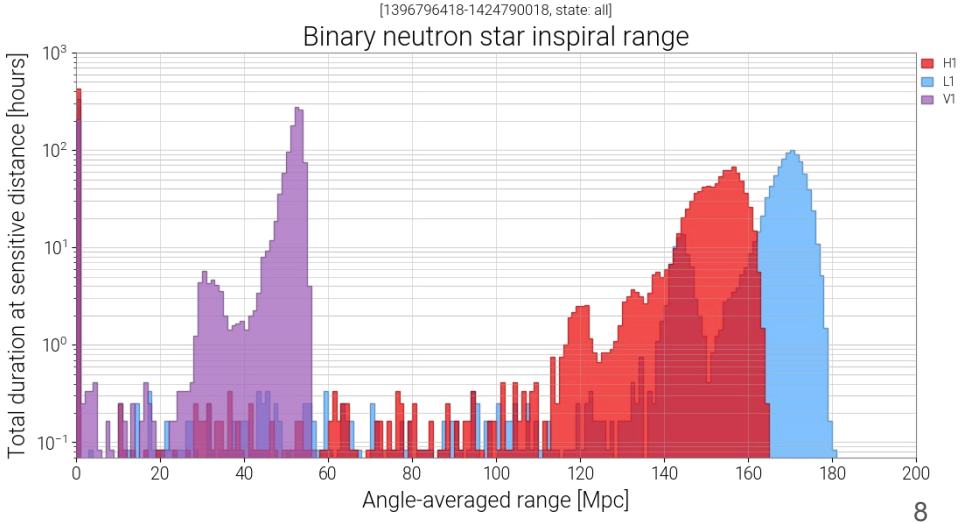
Current observing run (O4b)

Network duty factor

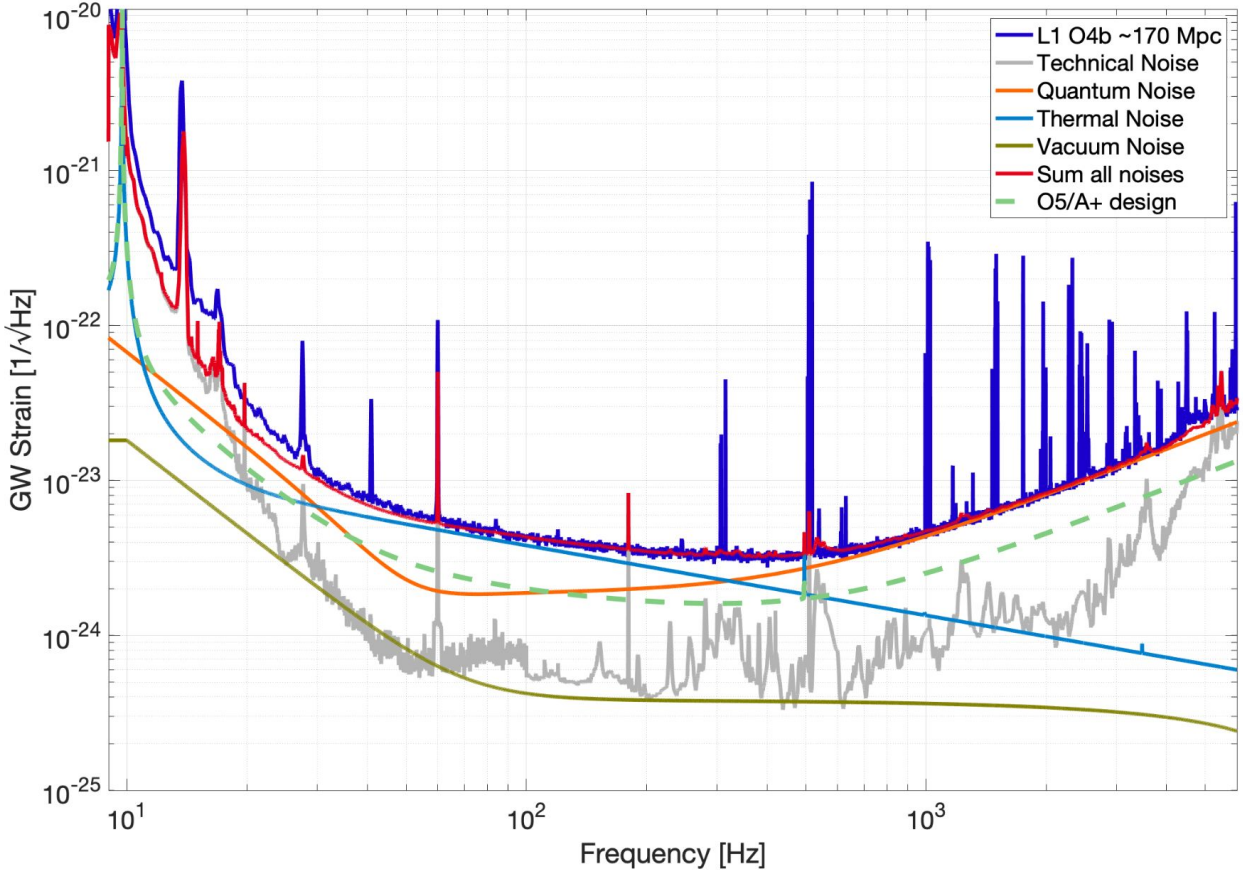
[1396796418-1401462444]

- Triple interferometer [46.3%]
- Double interferometer [33.8%]
- Single interferometer [11.6%]
- No interferometer [8.3%]



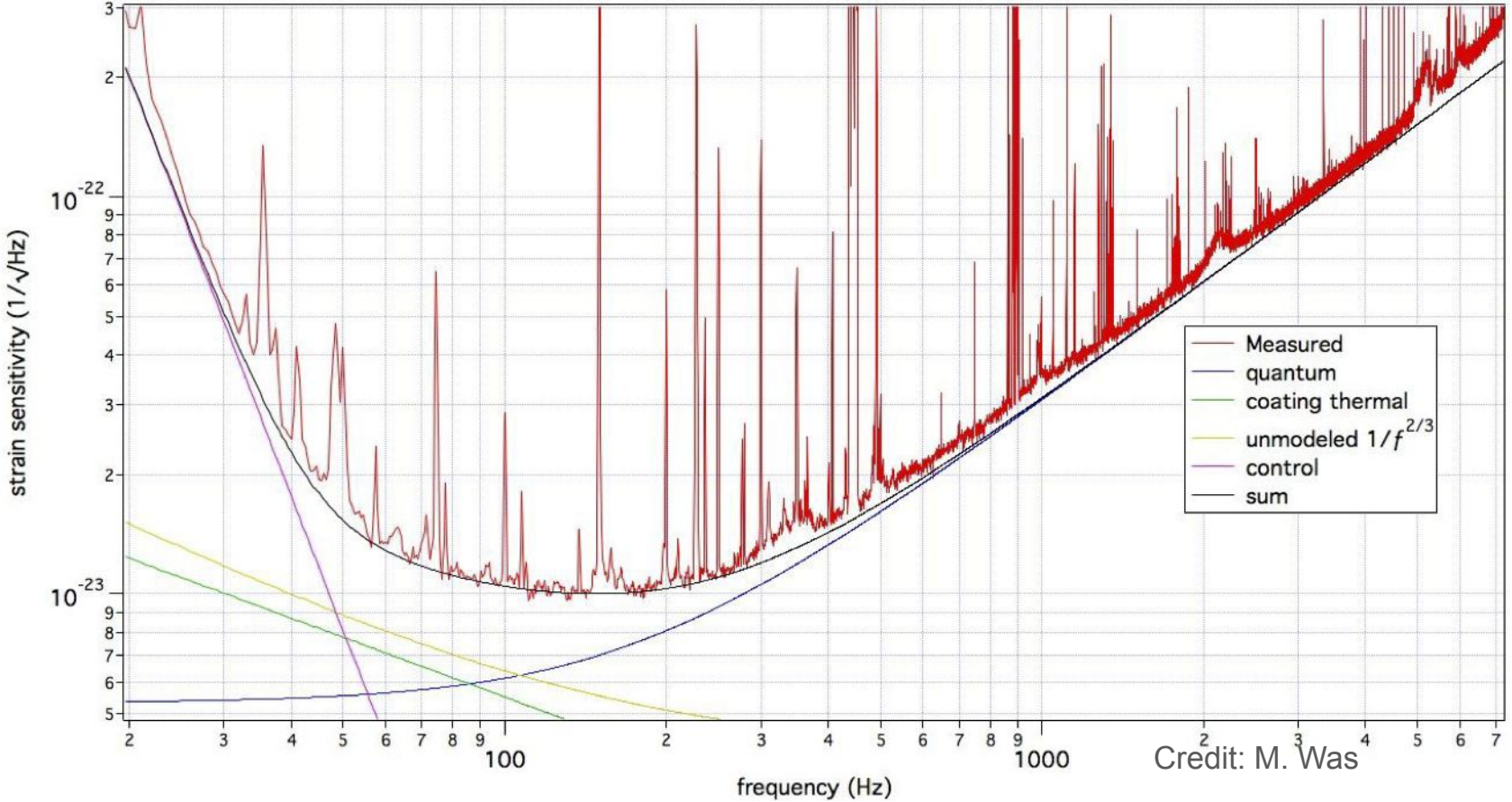


L1 Simplified Noise Budget



- Thermal noise most limiting!
- Still have unknown low frequency noise
- Have to reduce technical noise and losses if reducing quantum noise is to be effective

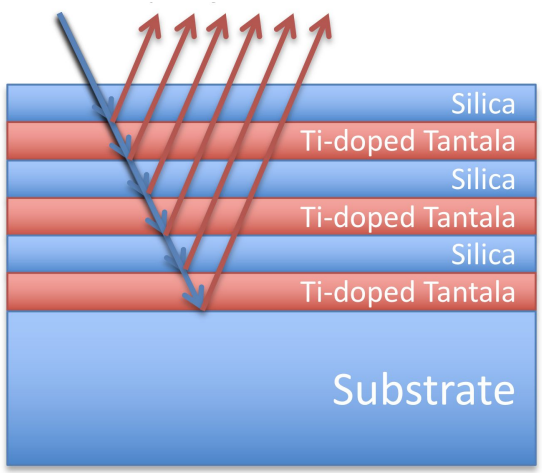
V1 Simplified Noise Budget



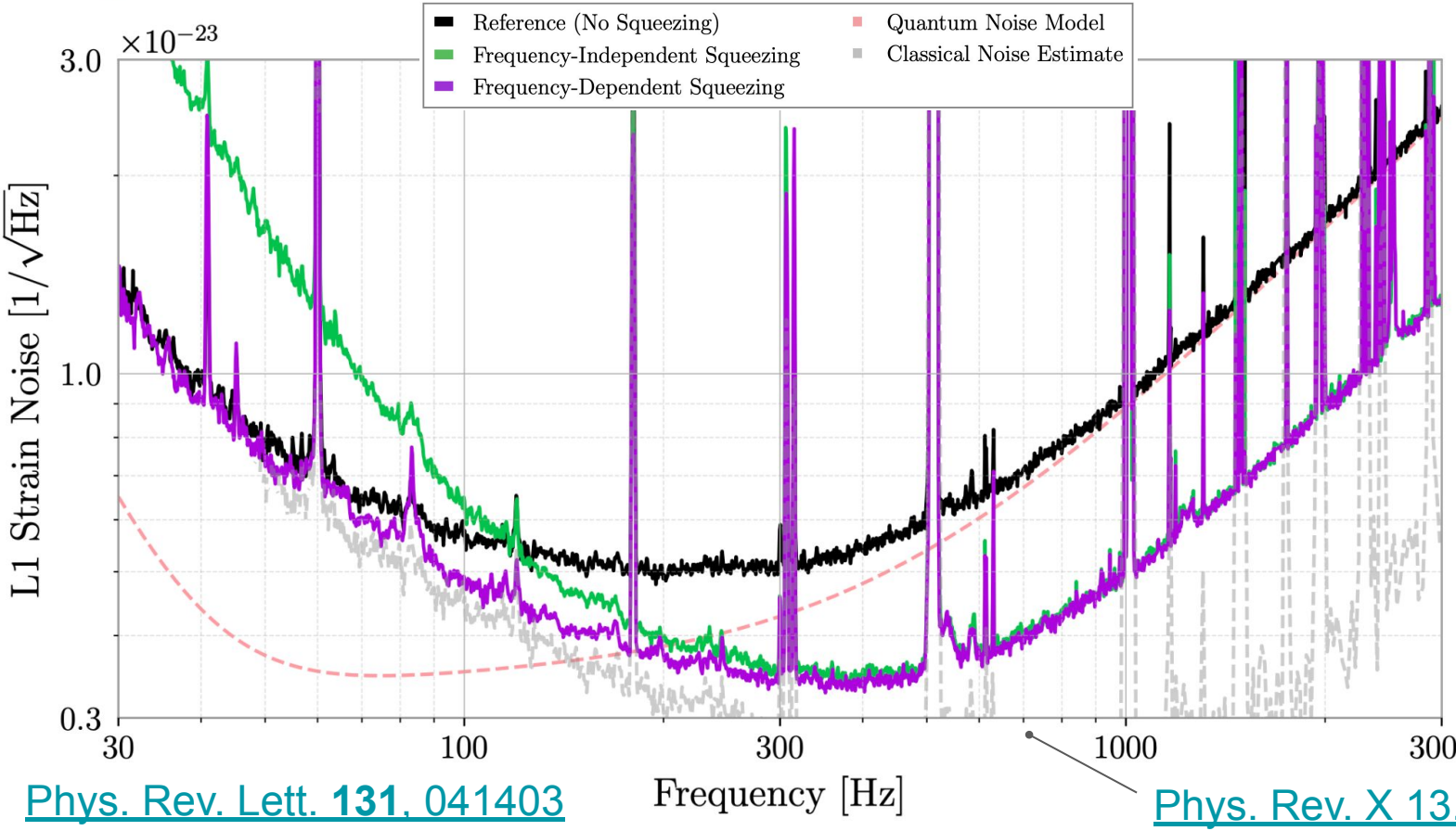
Credit: M. Was

One Technical Challenge: Coatings

- Thermal noise most dominant mid-frequencies is due to coatings
- many layers of interspersing low/high index
- Has to be larger than "usual" ~20cm diameter
- Fortunately lots of research ongoing on materials and procedures
- Virgo and LIGO working together to make a decision soon
- Will be done at LMA in France
- Goal is half current* thermal noise
- Other parameters matter:
  - Absorption (high power operations)
  - Point absorbers (high power operations)
  - Scatter



One Technical Success: Frequency-dependent Squeezing

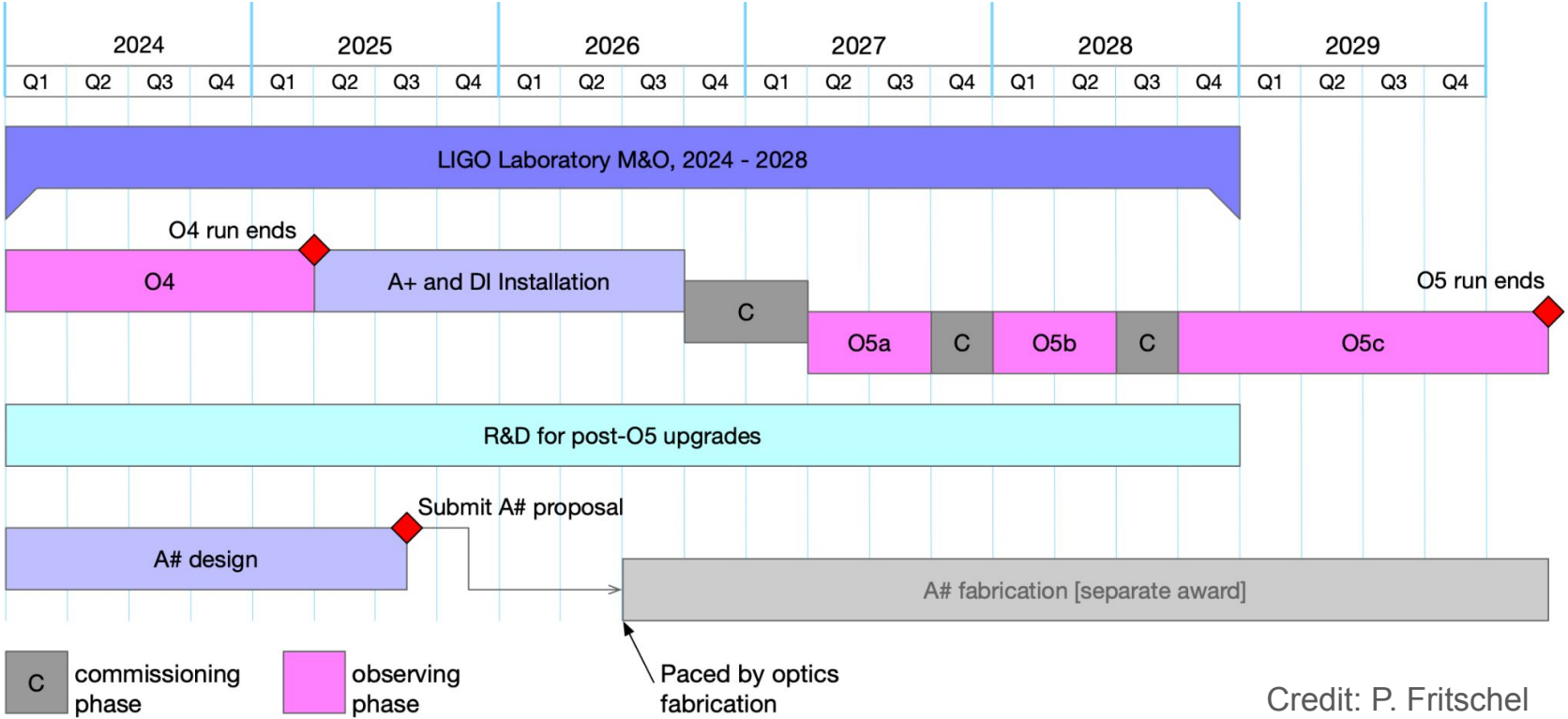


Phys. Rev. Lett. **131**, 041403

Phys. Rev. X 13, 041021

LIGO upgrade plan (A+/O5 and *A#/O6*)

O5 staged to achieve final goal sensitivity of ~320 Mpc, A# proposal work in progress



Likely to shift by another quarter

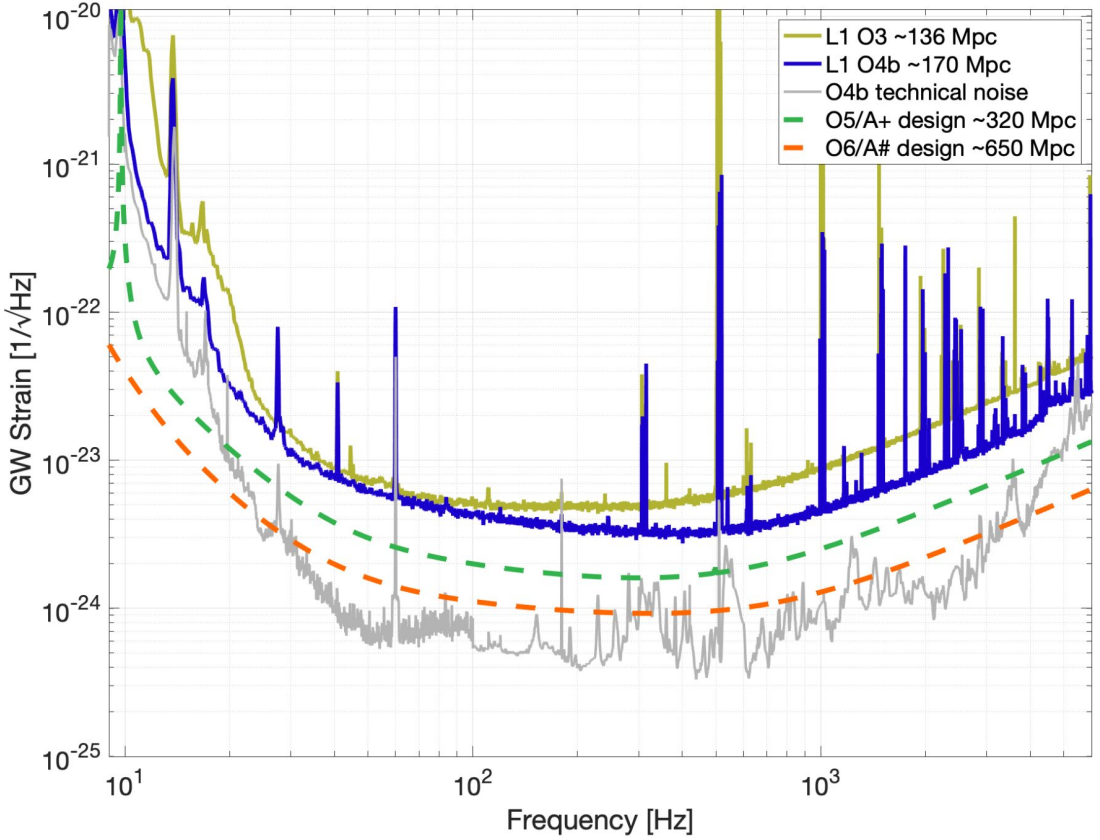
Credit: P. Fritschel

A# not funded, straw plan

LIGO Upgrade Goals

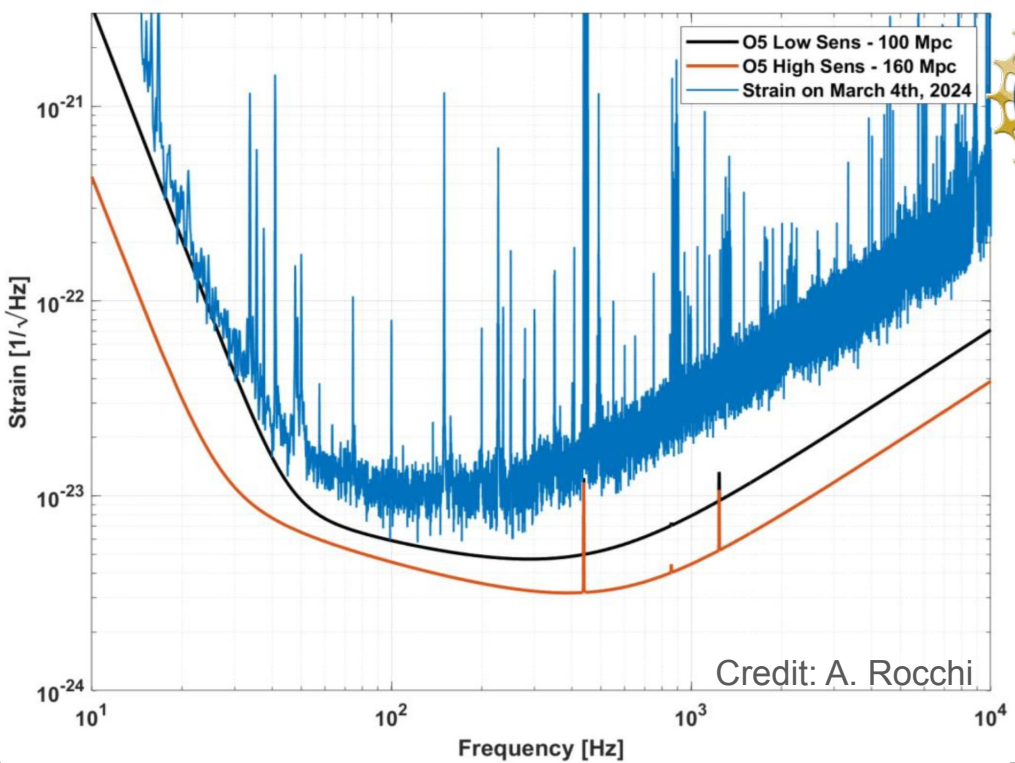
- A# requires:
  - Bigger test masses
  - More circulating power
  - More squeezing
  - Less technical noise
  - Better coatings than A+
  - Better seismic isolation

**A# shown here with AlGaS coatings*



Virgo Upgrade Plan

- implement stable recycling cavities - major civil works
- After O5 plan: **Virgo nEXT** very conceptual stage



	2024				2025				2026				2027				2028				2029			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Upgrade							civil works + vac installation							Upgrades installation and commissioning										
«O5»																								
«O4»																								

Credit: A. Rocchi

LIGO India

- Site acquisition complete
- Final approval May 1 2023
- Civil design complete
- Hope to be running 2030
  Later than initial plan…
- TBD exact configuration
  A+ separate funds

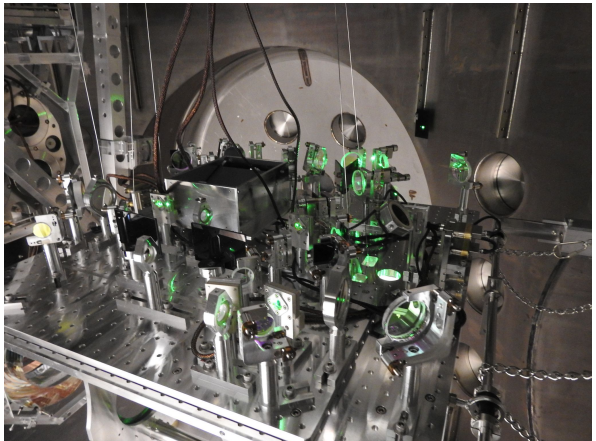
Aundha Observatory, Hingoli district

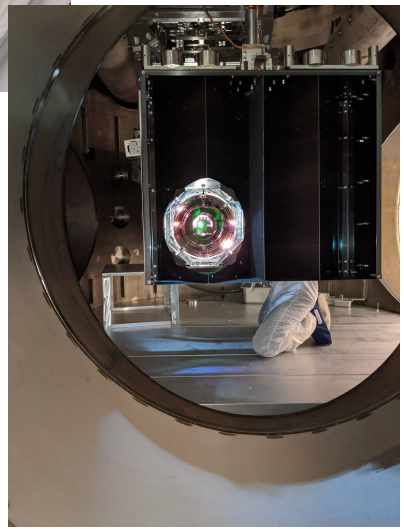
When 3G observatories come online (ET, CE), it could be that the current LIGO and Virgo are decommissioned. **But if we have good ideas for other experiments in the facilities, we should start planning now!**

LIGO India is best location(MPSAC report) to continue observing alongside 3G.

It could host further upgrades such as A# and/or Voyager (Si+cryo).

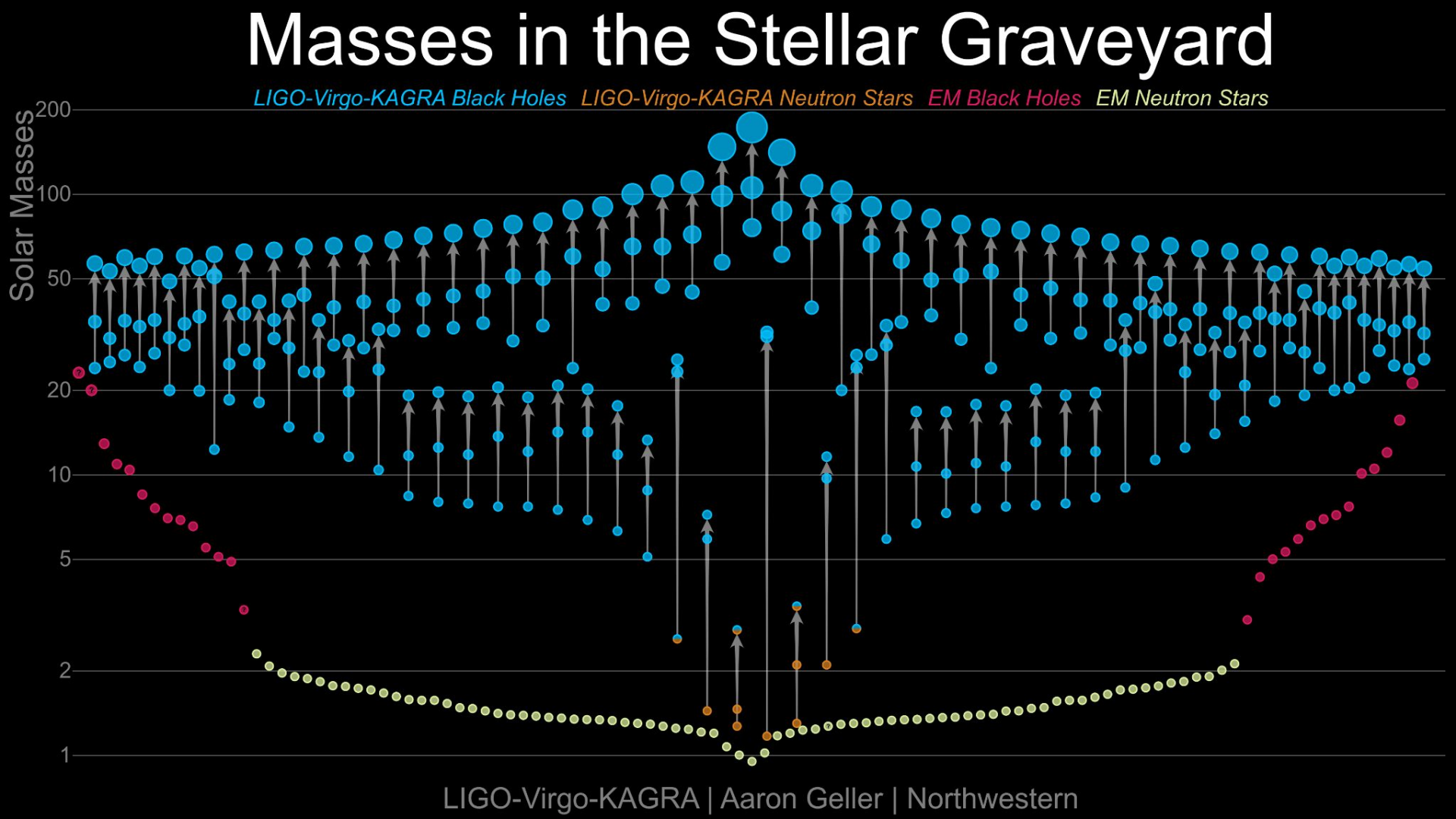
Thank you





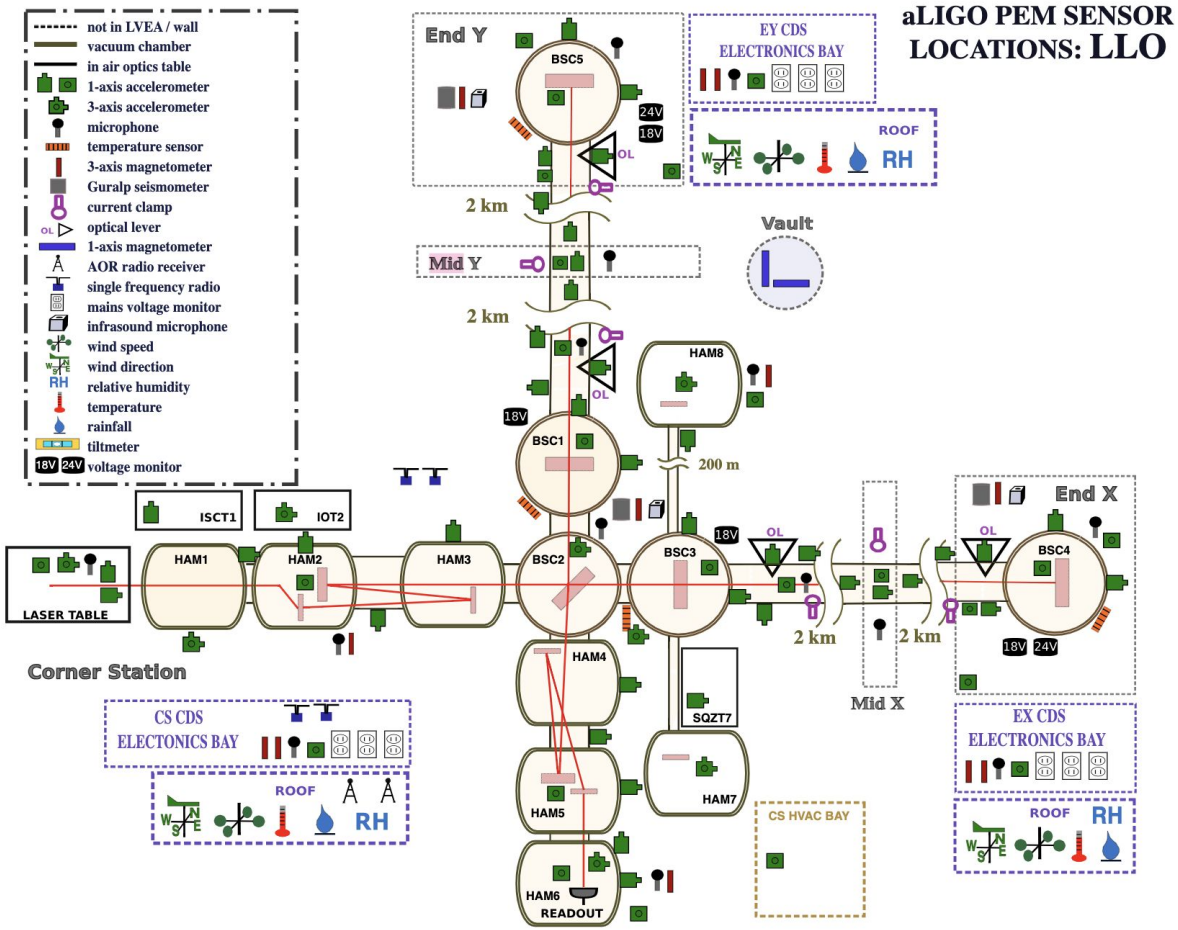
EXTRA SLIDES

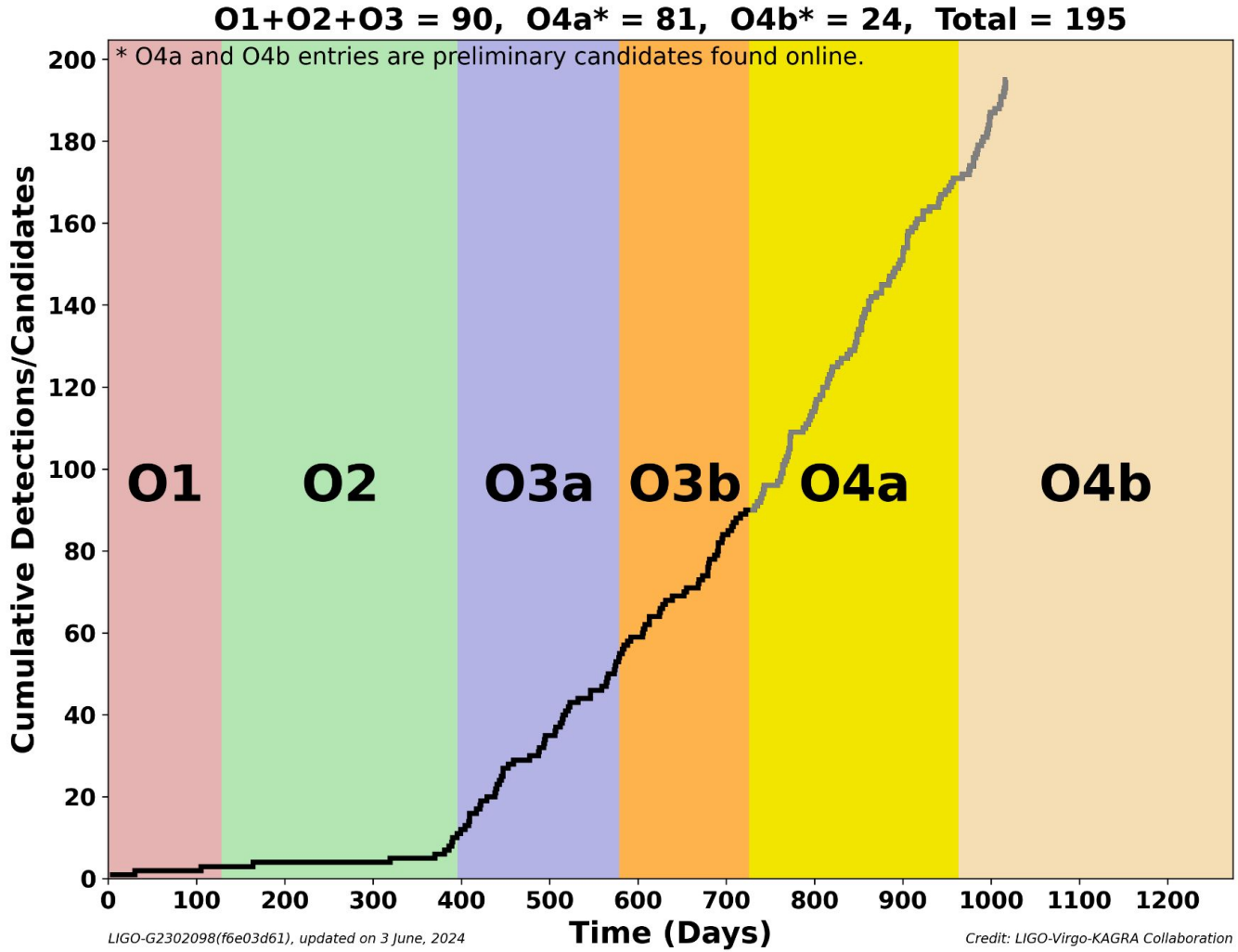
Masses in the Stellar Graveyard



M. Fyffe

My cup of tea - ambient noise studies




O1+O2+O3 = 90, O4a* = 81, O4b* = 24, Total = 195
* O4a and O4b entries are preliminary candidates found online.
Cumulative Detections/Candidates
Time (Days)
O1
O2
O3a
O3b
O4a
O4b
0
20
40
60
80
100
120
140
160
180
200
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
LIGO-G2302098(f6e03d61), updated on 3 June, 2024
Credit: LIGO-Virgo-KAGRA Collaboration

Title

Text:

-