
LIGO
NSF
Can you get there from here?
Thinking about paths from AdV+/A+ to 3 G
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with minor additions from McClelland and Shoemaker
Dawn IV
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LIGO-G1801680
Caltech
LSC
MIT

Outline

- Perspective on A+
  - *Can someone offer symmetrical view for AdV+? Sorry, was planning to do more homework.*
- Constraints: real vs. imagined
- “Baby steps” vs. “Giant Leaps”
- Some ideas

A+ ‘elevator pitch’

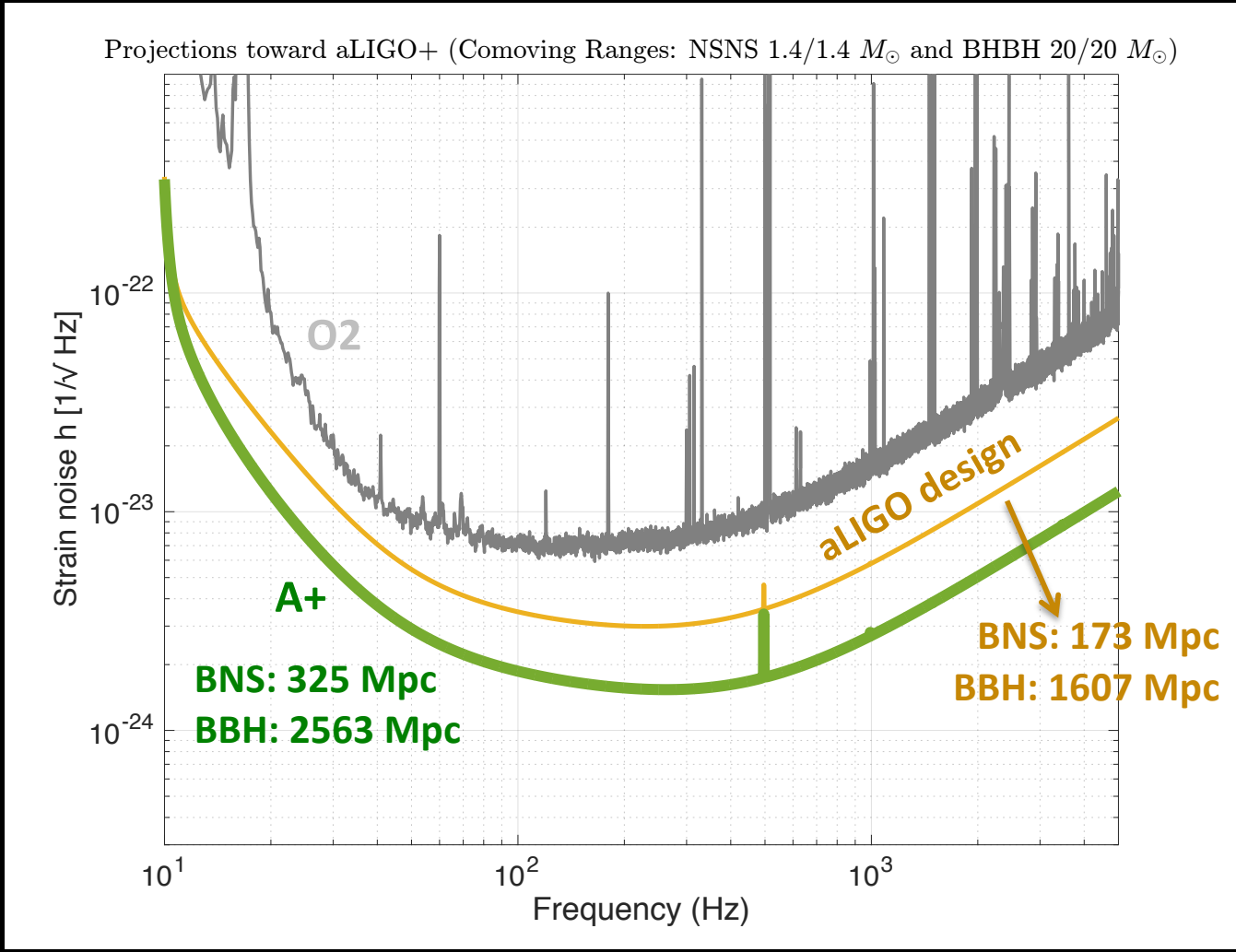
(we’ll come back to this later)

- An incremental upgrade to aLIGO that leverages existing technology and infrastructure, with minimal new investment, and moderate risk
- Target: factor of 1.7* increase in range over aLIGO
  - ➔About a factor of 4-7 greater CBC event rate
- Bridge to future 3G GW astrophysics, cosmology, and nuclear physics
- Stepping stone to 3G detector technology
- Can be observing within 6 years (mid- 2024)
- “Scientific breakeven” within 1/2 year of operation
- Incremental cost: *a small increment on aLIGO*
- *Joint international effort: ~ 35% UK and Australia funding*

*BBH 30/30 $M_\odot$: 1.6x
*BNS 1.4/1.4 $M_\odot$: 1.9x

A+: a mid-scale upgrade to Advanced LIGO

- Reduced quantum noise
  - Improved optical losses
  - Improved readout
  - Frequency-Dependent Squeezing
- Reduced thermal noise
  - Improved mirror coatings
- Observing by mid-2024



Selected A+ Discovery Targets

Based on P170608 and P170817 rate density estimates:

BBH rate 4.1x aLIGO → ***17-300 BBH/month***

Off-axis observations → *BH component spins*

BH Spins → *Origins of stellar-mass BH*

Z_{max} ~ 1.5 → *BBH cosmological evolution*

SNR ~ 100 → *Ultra-precision tests of GR*

BNS rate 6.7x aLIGO → ***1-13 BNS/month***

(2-11 BNS x SGRB coincidences/year)*

Multimessenger coincidences → *precision H_0 measurement, kilonovae, etc.*

High inspiral SNR → *BNS tidal deformation*

BNS remnant "ringdown" → *NS matter equation of state*

(or more, if GW170817 represents hidden sub-threshold SGRB population)

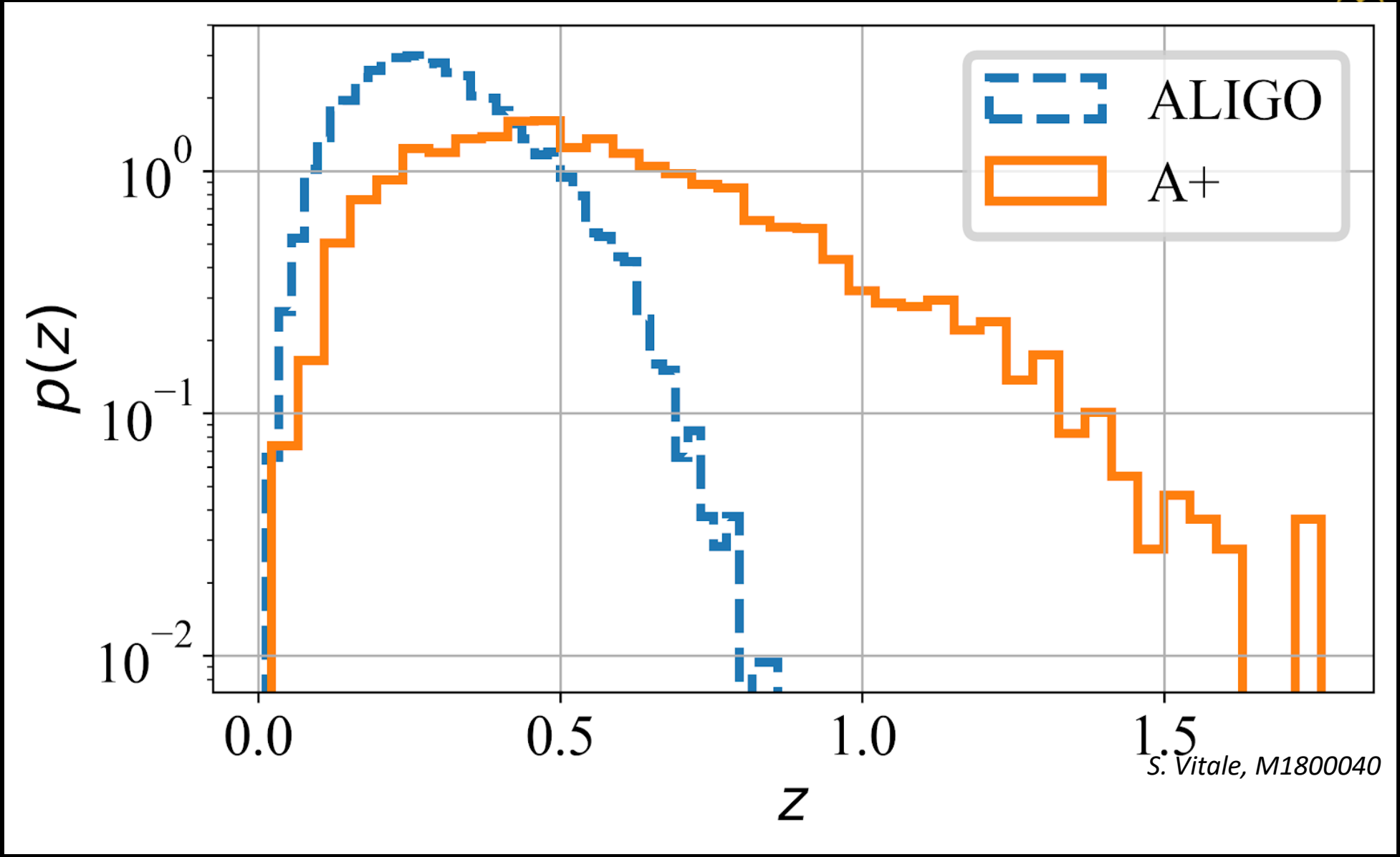


Figure 7: Redshift distribution of binary black hole sources detectable with SNR > 10 in a single A+ detector, as compared to baseline aLIGO at design sensitivity.

BNS post-merger “ringing” vs. NS EOS

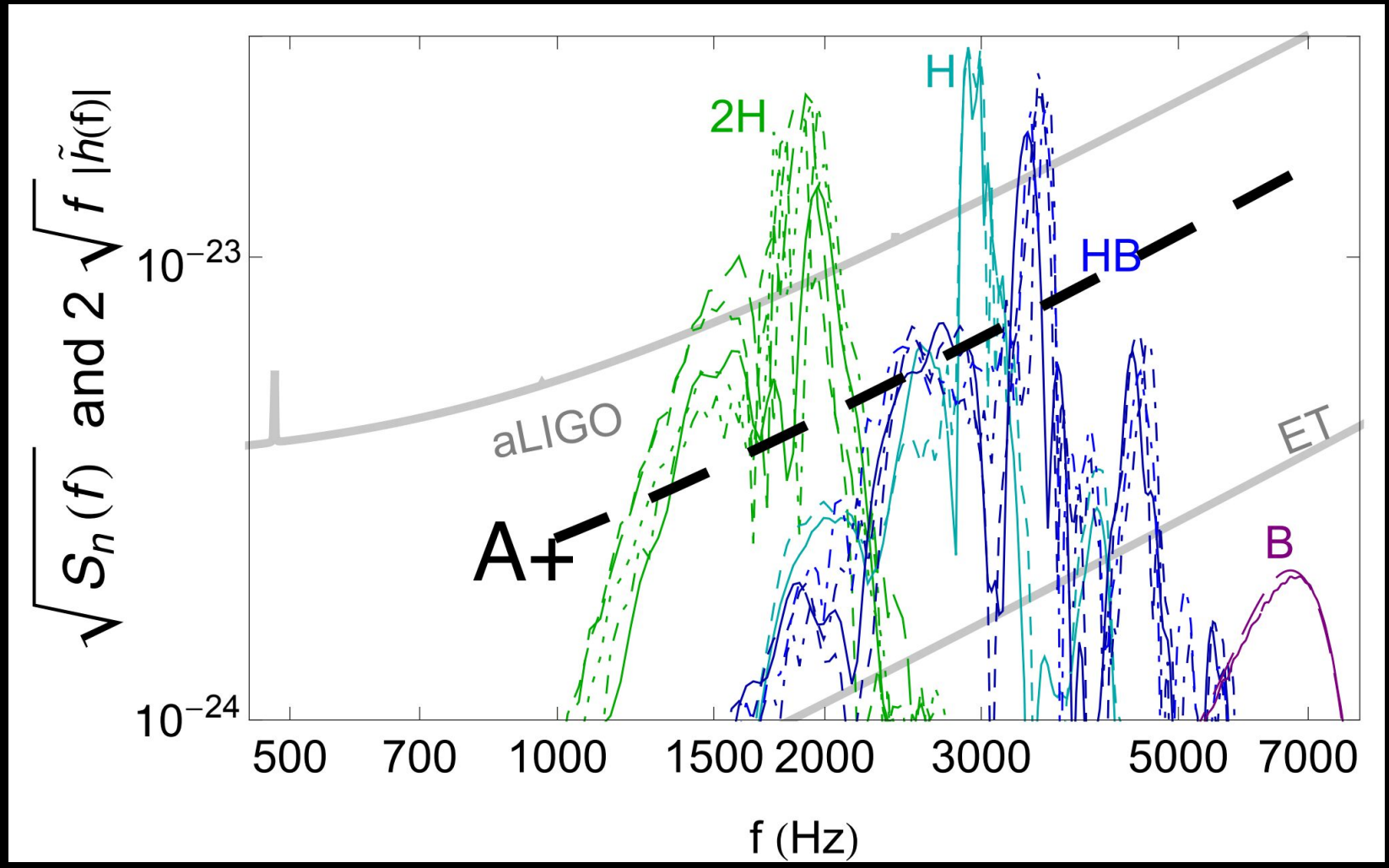


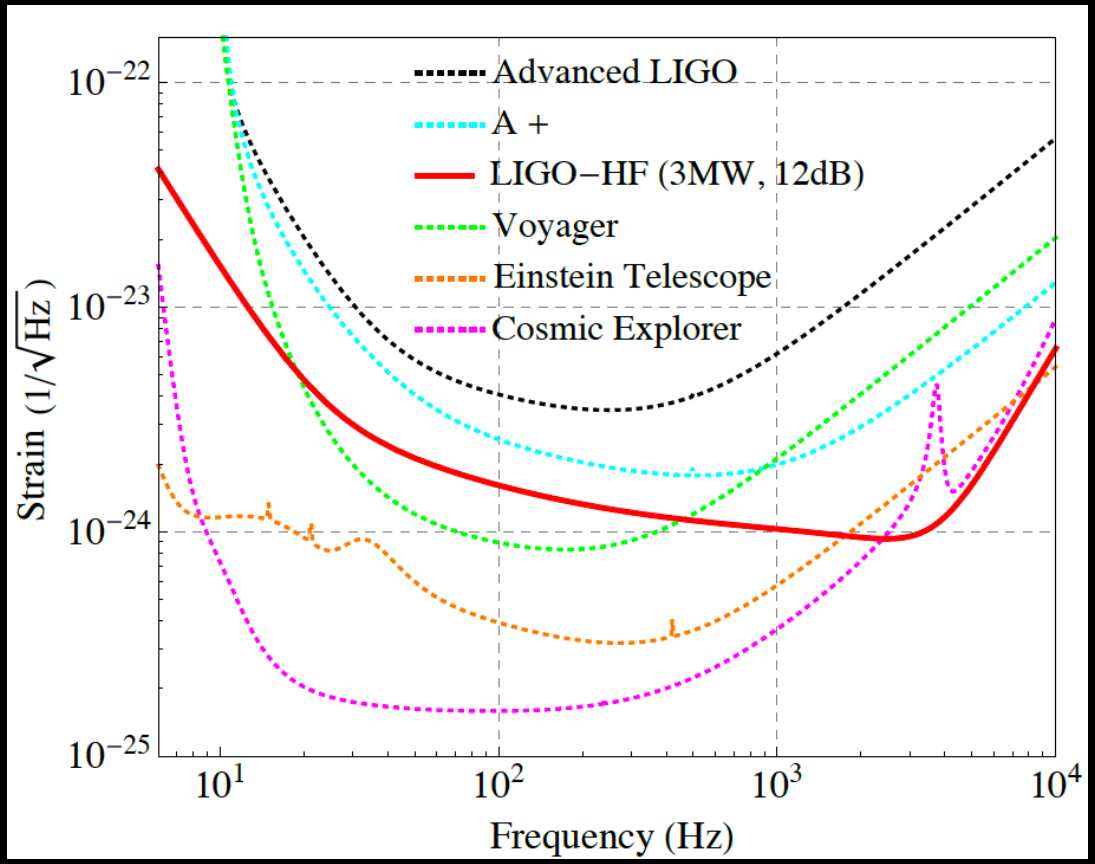
Figure 6: BNS post-merger signal models vs. aLIGO and A+ detector noise for a range of speculated neutron-star equations of state (labeled 2H - B). A+ will have significantly improved capacity to detect post-merger "ringing" modes, whose characteristic frequencies are determined by the equation of state of super-nuclear matter. The low-frequency inspiral waveform component, which can also bear signatures of tidal deformability in the progenitor stars, is not shown. Simulations presume a reference BNS coalescence at 100 Mpc. (courtesy J. Veitch and S. Vitale, adapted from Read et al. [31])

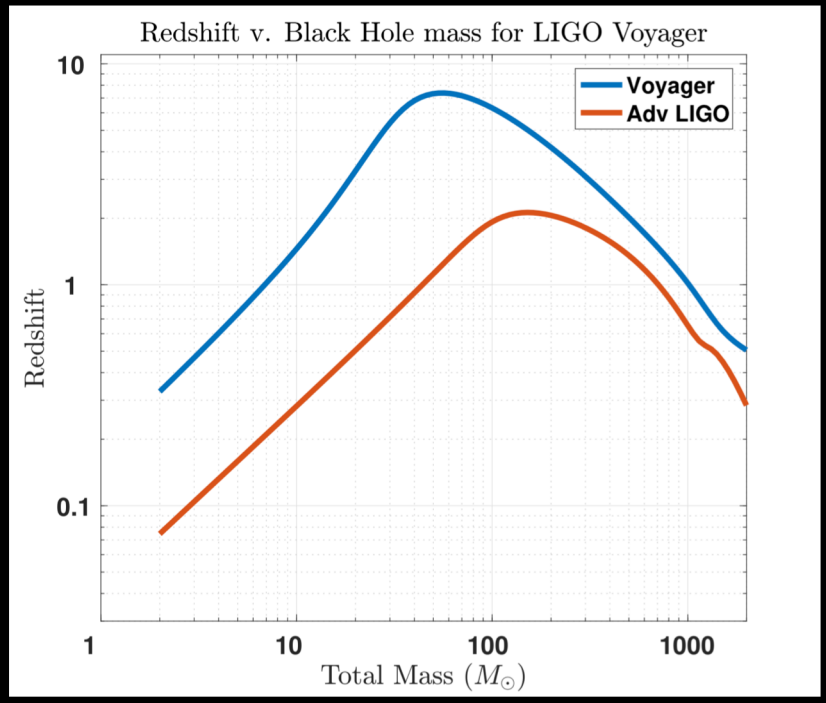
A+ Upgrade Status

- NSF awarded US funds, 18 months earlier than original request
  - Same end date (4QFY2023, limited by COC coatings) but *much faster start*
  - Acceleration may allow facility and vacuum upgrades between O3 and O4
  - Retires risk, may well accelerate commissioning and O5 (no promises!)
  - LIGO Lab team has formed and mobilized; formal start in 1 month, 10/1/2018
- Australian ARC funding has already been awarded
- Companion UK proposal is now under UKRI/STFC review
  - We are cautiously optimistic for a similar accelerated UK start
  - This would relieve schedule pressure on core optics polishing (sequential fabrication) and suspension design pipelines

Big picture: we expect LIGO will be observing with A+ sensitivity by late 2024

Beyond A+


Advanced LIGO
A +
LIGO–HF (3MW, 12dB)
Voyager
Einstein Telescope
Cosmic Explorer
Strain (1/√Hz)
Frequency (Hz)
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{1}
10^{2}
10^{3}
10^{4}


Redshift v. Black Hole mass for LIGO Voyager
Voyager
Adv LIGO
Redshift
Total Mass ($M_\odot$)
10
1
0.1
1
10
100
1000

A+ ~~elevator pitch~~ *constraints*

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Look at all the constraints:

- "Your next investment should…
  - …be incremental in cost
  - …minimize loss of observing for existing instruments
  - …provide immediate scientific return
    - e.g., improved *rate*time* integral should 'quickly' wipe out observing hiatus due to upgrade
  - …build upon and fully exploit *prior* investment
    - "we already invested 10^9 $/€/£…"
  - …simultaneously support *following* investments, e.g.,
    - test technology for "(n+1)G"
    - probe future astro source landscape

…all the constraints (2):

- All good and wholesome, but taken together, recipe for a *holding pattern*
- Nothing big happens that way
  - (certainly not Initial or Advanced LIGO)
- Which constraints to challenge here?
  - (really asking, I don't know).

Are there other constraints we *should be* considering?

- For example:
  - We naturally fret about seismic, quantum and thermal noise
  - Our reviewers (perhaps the more influential ones?) may fret about 15% cost growth in steel, earthmoving, or concrete
    - Even “routine” roads and tunnels see 100% overruns
  - Are we investing responsibly to bound and manage large, “conventional” risks, or are we only looking after the novel “interesting” ones?

Suggestion: diversify

- Increments like A+, AdV+ and Voyager are necessary, but too overconstrained to put us in the strike zone
- Always the possibility of a visionary patron and a leap of faith; hope for this, but can't plan on it
- *3G technology demonstration* investments can retire investment risks
  - Without interfering with 2/2.1/2.5G observations
  - Without forcing 'profitable' integration on an existing (obsolete) instrument
- LIGO and Virgo invested millions and decades to pre-qualify
  - beamtube construction;
  - phase noise at the MIT 5m;
  - displacement noise at the CIT 40m;
  - optic polishing, metrology & coating pathfinders;
  - etc.
- What are the analogs for 3G?

Possible “Large-scale” 3G technology demonstration investments

- 3G Value-Engineered Beamtube Demo
  - LIGO is planning a water vapor desorption test on a spare 7m tube section at LLO
  - NSF just funded a LIGO workshop for early ‘19 on Very Large Scale Vacuum Systems
  - What about a 500m scale 3G beamtube fabrication and degassing test?
- 3G Tunnel/Earthwork Demonstration
- 3G Very Large Optic Polishing & Coating Pathfinder
- …?...(ideas welcome)

Discussion points

- Nobody wants to wait
- Nobody wants to invest 10-100M $/€/£ in engineering demo projects that don't detect GW's

BUT

- Moving directly to full scale design without some proofs of concept may meet resistance
- We can't demonstrate all of what we need on H1/L1/V1/K1/I1
- We probably need to break *all* the risky problems (not just the interferometry) into pieces and show what we can do in each domain separately.
- *What impact do increments like A+, AdV+, A+ HF and Voyager have on the 3G case and network planning?*

A few questions for the 'Voyager Epoch'

- how long will A+/AdV+ be interesting for observing
- what cost scales are involved in making another 1.5-2x improvement in the instruments
- when do those costs fall on funding agencies wrt to the CE/ET costs
- what roles do these 2.5-2.75 generation play for CE/ET in terms of risk-reduction prototypes
- what level of constructive and destructive interference will these projects have on parallel demands to get ET/CE designed/fabbed
- do we want to deploy one of the world network instruments as a 2.75G system as a test, or multiple ones to increase the network sensitivity


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THANKS
(and sincere apologies from MZ)
Caltech
LSC
MIT