3G Science Case
Binaries Group update

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Key science goals

These connect different types of **stellar system**

- containing different combinations & varieties of black holes and neutron stars (and white dwarfs?)

with different **signals or samples**

- events seen with such high signal-to-noise ratio that astrophysical quantities can be inferred with exquisite precision;
- the discovery of signals from previously-unseen classes of events;
- observations that reach the edge of the visible Universe, probing the whole of cosmic time;
- large ensembles of events that provide high statistical significance for population-scale observables.

Key science goal 1

Discover compact objects throughout the observable Universe and explore their demographics:

(i) Observe merging black holes to the beginnings of the reionization era and neutron stars to the peak of the star formation rate.

(ii) Uncover the merger rate and properties (masses, spins, orbital eccentricities) of compact mergers as a function of redshift, and measure any correlations between them.

(iii) Compare these demographics to the cosmic evolution of star formation rate, metallicity, and possibly host galaxy types.

Key science goal 2

Reveal the fundamental properties of stellar- and intermediate-mass black holes (BHs) with the goal of uncovering their origins:

(i) Measure any mass gaps or cut-offs in the black-hole mass distribution due to physical processes in compact object formation.

(ii) Are black-hole spin magnitudes and tilts correlated? Are they correlated with mass?

(iii) Determine the population or single-source features that can help us identify specific formation channels (e.g., masses, spin orientations, merger time delays, eccentricities). If multiple channels are important, infer the relevant branching ratios.

Key science goal 3

Explore the diversity of neutron star (NS) formation mechanisms through the precise measurements of NS masses in binary mergers across cosmic time:

(i) What is the distribution of NS masses?

- Is there bimodality in the NS mass distribution?
- Are NS masses in NS-BH mergers different than in NS-NS mergers?
- Do all or the majority of NS-NS binaries have mass ratios very close to unity?
- Is the answer to this question redshift- or metallicity-dependent?

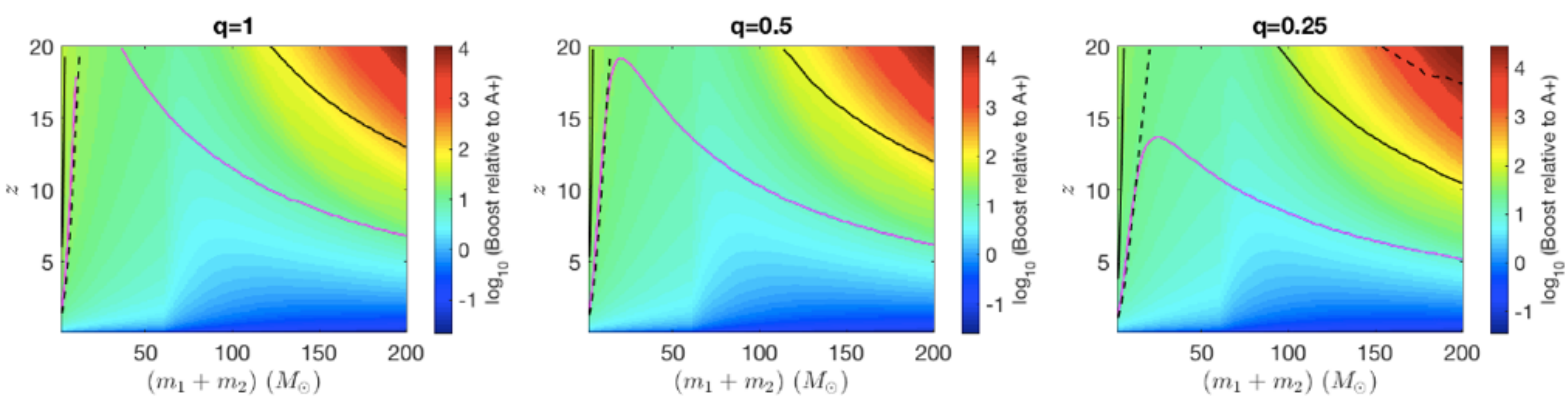
(ii) Is there evidence for NS formation through white dwarf mergers?

(iii) Can we constrain NS spin magnitudes and orientations, and thereby infer their origins?

(iv) Can associations with host galaxies and offsets constrain kicks imparted by SNe?

Technical question 1: detector reach

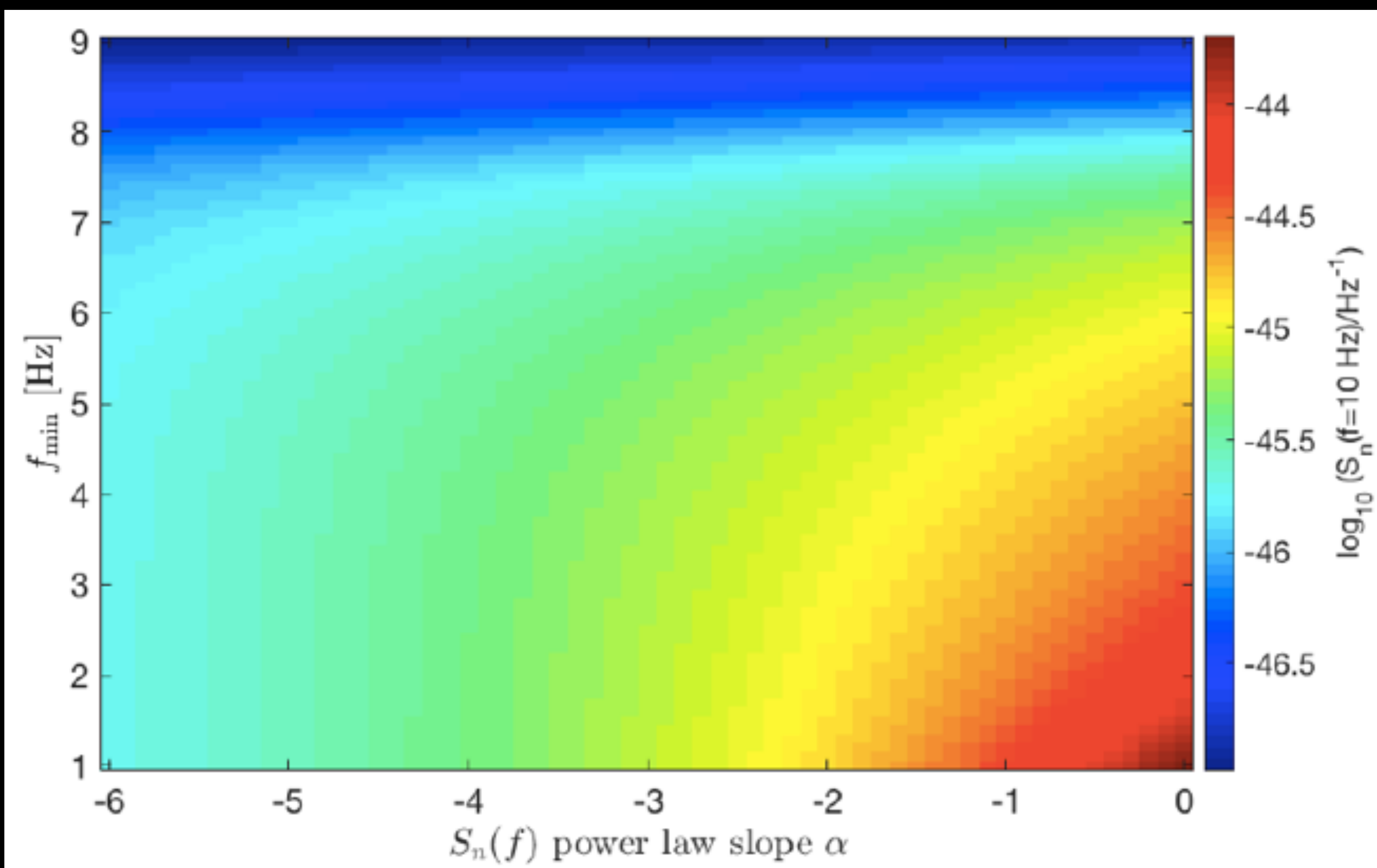
What boost factor relative to LIGO A+ is required to detect an optimally-oriented, overhead binary of a given total at an SNR of 8 at a given redshift?



A detector 10 times more sensitive than LIGO A+ would be sufficient to observe favorably located and oriented binary neutron stars to a redshift z=1.8, near the peak of star formation, and equal mass binary black holes with component masses between 5 and 20 solar masses to z~20. A boost factor of 30 would be sufficient to observe binary neutron stars to z~10.

Technical question 1: high masses and low frequencies

Use the detectability of a binary of two 100-solar-mass intermediate mass black holes at z=10 to place requirements on low-frequency sensitivity.

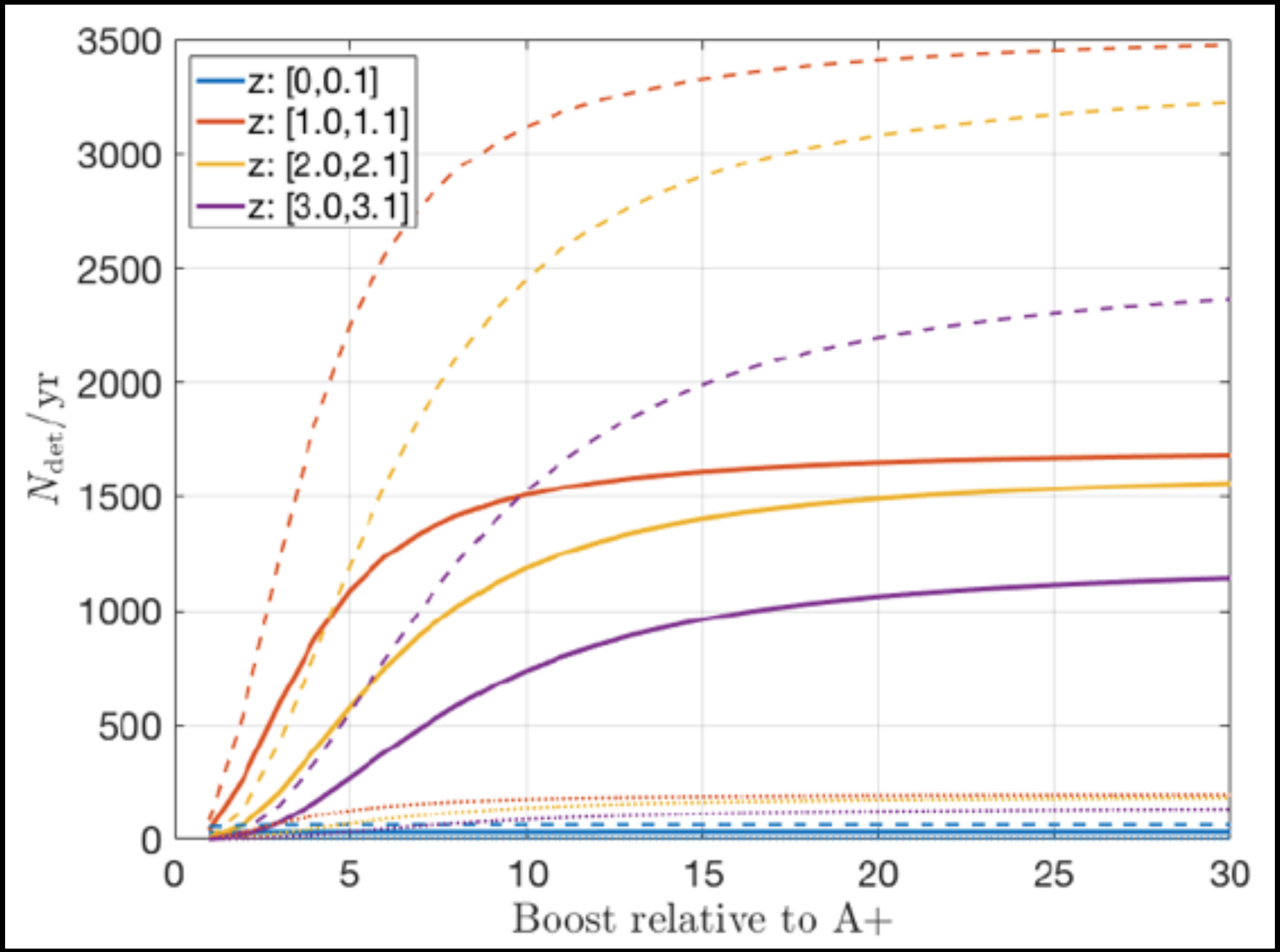


A detector with noise PSD

S_n (f=10 Hz)=10^{-45} Hz^{-1}, i.e., 10 times more sensitive than LIGO A+ at that frequency, can detect this IMBH binary if it has a $S_n(f) \sim f^{-2}$ noise spectrum extending down to 1 Hz, or a flat noise spectrum between 6 and 10 Hz.

Technical question 2: recovering the BH mass distribution

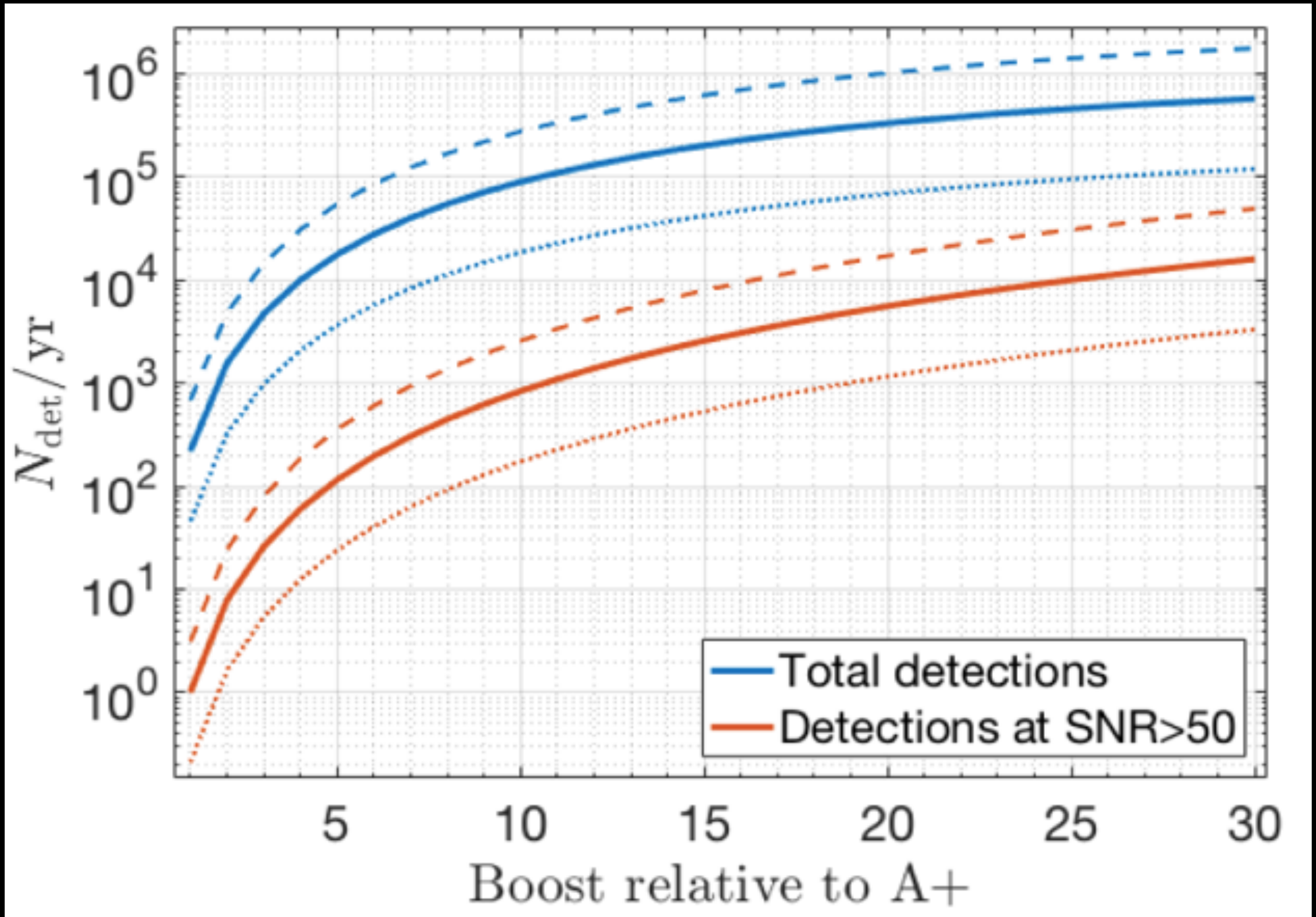
Need ~1000 detections in each Δz=0.1 bin to measure boundary of (P)PISN [NS-BH] mass gap to an accuracy of 1 (0.3) solar masses as function of z



The goal of ~1000 detections per redshift bin is achievable with boost factors of 5 to 10 relative to LIGO A+ for the median BBH merger rates inferred assuming a power-law in mass distribution.

Technical question 3: recovering the NS mass distribution

Need ~10000 detections to measure the maximum NS mass an accuracy of 0.03 solar masses and ~1000 high-precision observations (SNR>50) to measure the NS mass distribution



Boost factors of 4 (3, 7) relative to LIGO A+ needed to detect 10,000 sources assuming the median (upper and lower 90\% credible interval boundary) BNS merger rate. Boost factors of 10 (7, 20) required to for 1000 precision observations.

Where we stand

- Current draft in github
- Representative technical requirements developed
- Writing team is working on the text
- Plenty of work left to do to complete the text, edit it, and review it — we will need your help!

Steps going forward

- Interface with other groups, especially in areas of overlap, e.g.:
    - Intermediate-mass BHs with seeds group
    - Primordial BBHs and stochastic backgrounds from binaries with cosmology group
- Complete text edits, resolve formulation of secondary science goals, update references
- Internally review the draft within the larger binaries group: this a statement for our community