# Designing a Next-Generation Gravitational-Wave Detector Network

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# What should a network of 3G detectors look like?

*Where should we place them?*

*How many of them should there be?*

*How long should they be?*

*Etc.*

# How to answer

*Write down network and detector parameters:*

- *Number, location, and orientation of detectors*
- *Length of detectors*
- *Optical design of detectors*
- *Etc.*

*Write down science goals:*

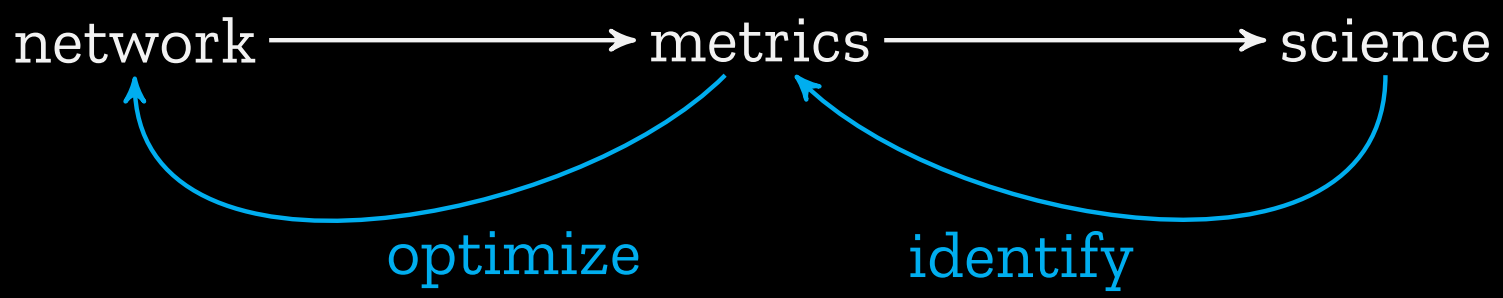
- *Neutron-star physics*
- *Stellar history and black hole formation via CBCs*
- *Tests of relativity*
- *Standard siren and multi-messenger astronomy*
- *Etc.*

*Perform some optimization routine.*

# Metrics

Optimizing network parameters directly from science goals is hard and ill-defined!

We should try to identify metrics that link the two:



# Some previous work

- Raffai et al. [1] and Hu et al. [2]:
  - Numerically optimize detector placement for 2G (aLIGO) and 3G (ET) networks
  - Figures of merit: polarization sensitivity, sky localization, and chirp mass reconstruction
- Vitale et al. [3, 4]:
  - Evaluate CBC parameter estimation capabilities for networks with 3G detectors
- Mills et al. [5] and Zhao et al. [6]:
  - Localization capabilities for networks with 3G detectors
- Michimura et al. [7]:
  - Optimize Kagra configuration to improve range or sky localization

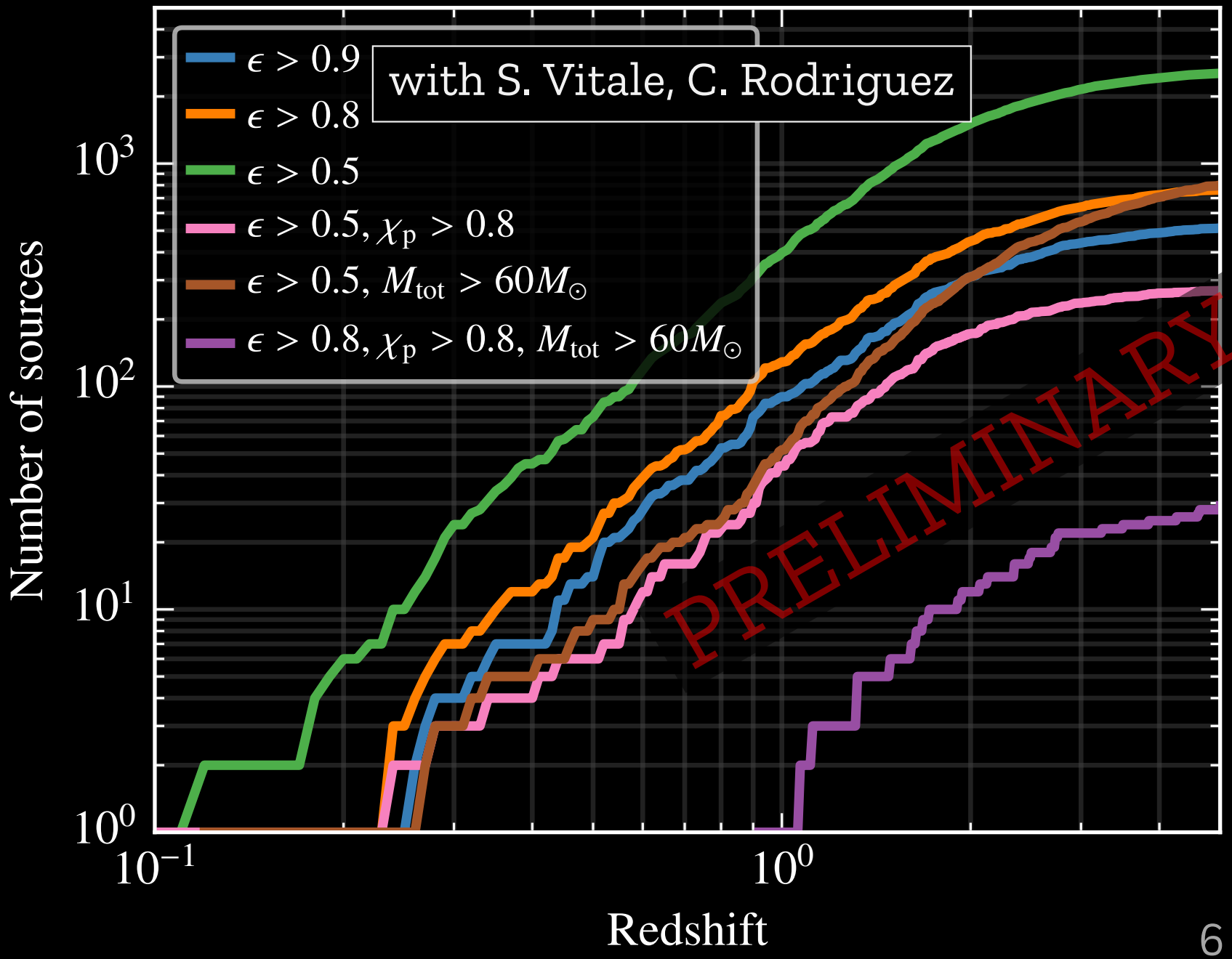
# What metrics to evaluate

Strawman list of metrics:

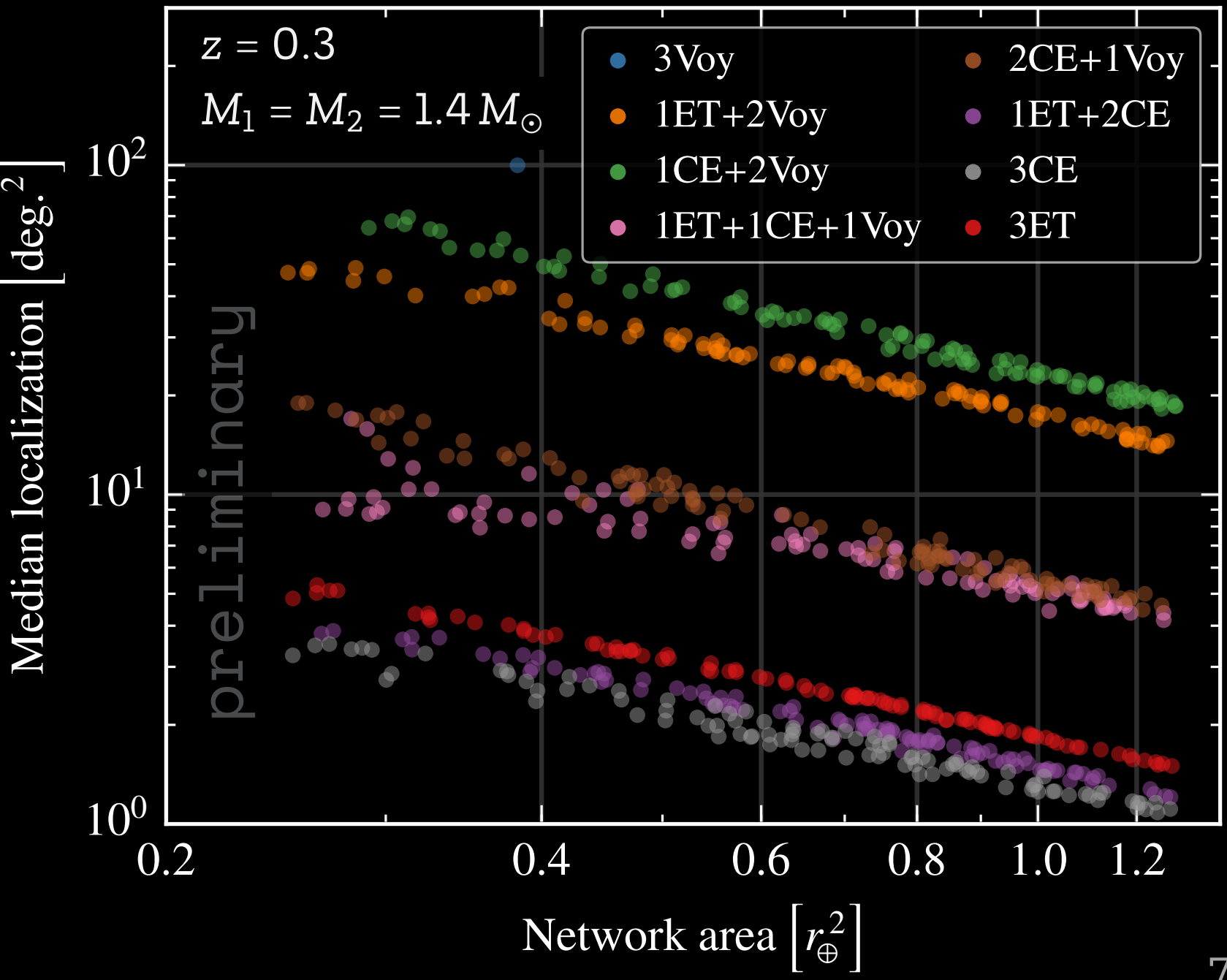
- CBC mass uncertainty
- CBC distance and inclination uncertainty
- CBC localization
- CBC signal-to-noise ratios
- Integrated strain sensitivity above 500 Hz
- Polarization sensitivity

(Where applicable, each metric evaluate at redshift $z \in \{0.1, 0.3, 1, 3, 10, 30\}$ and total mass $M \in \{3, 10, 30, 100, 300\}$)

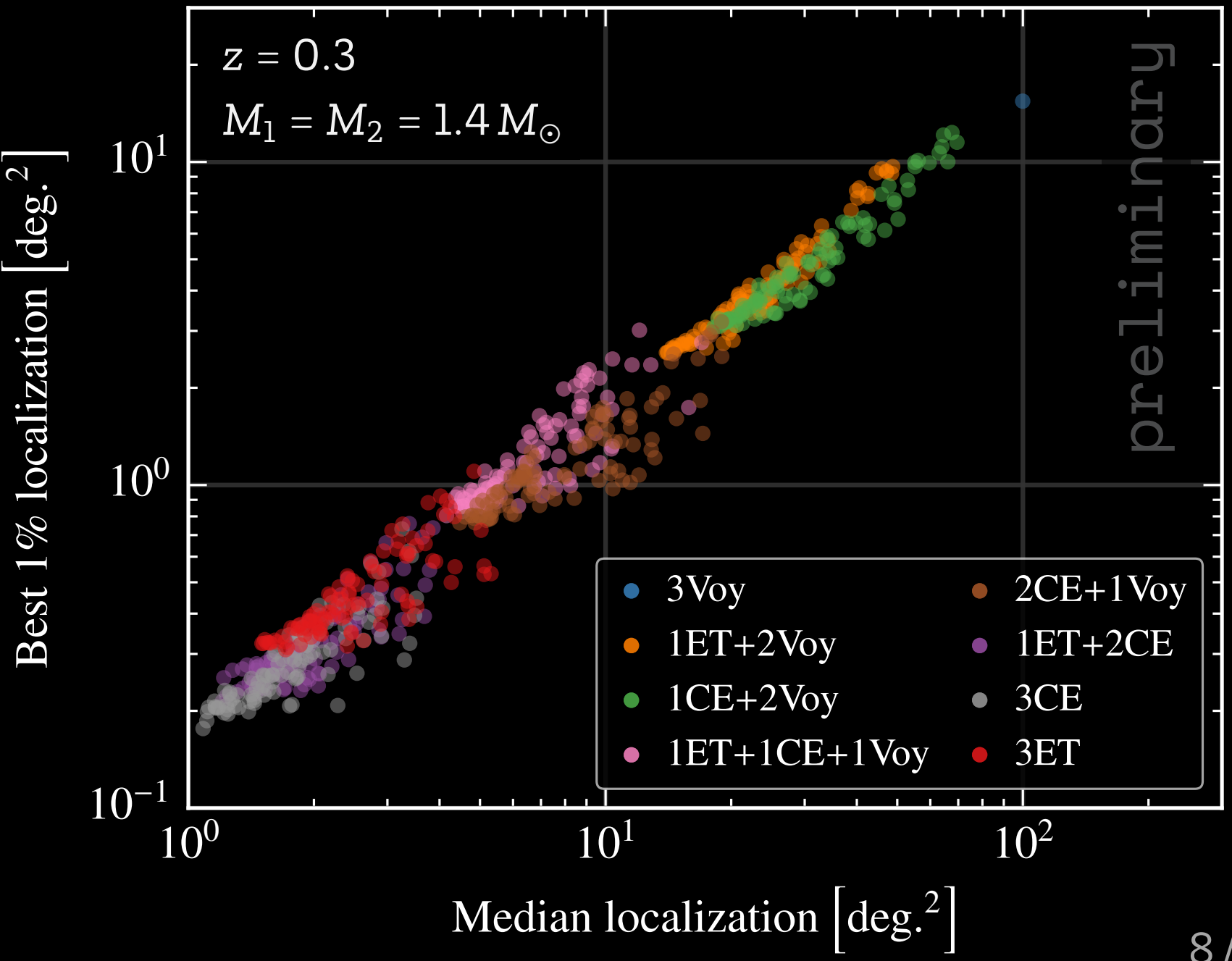
# What about the "rare" coalescences?



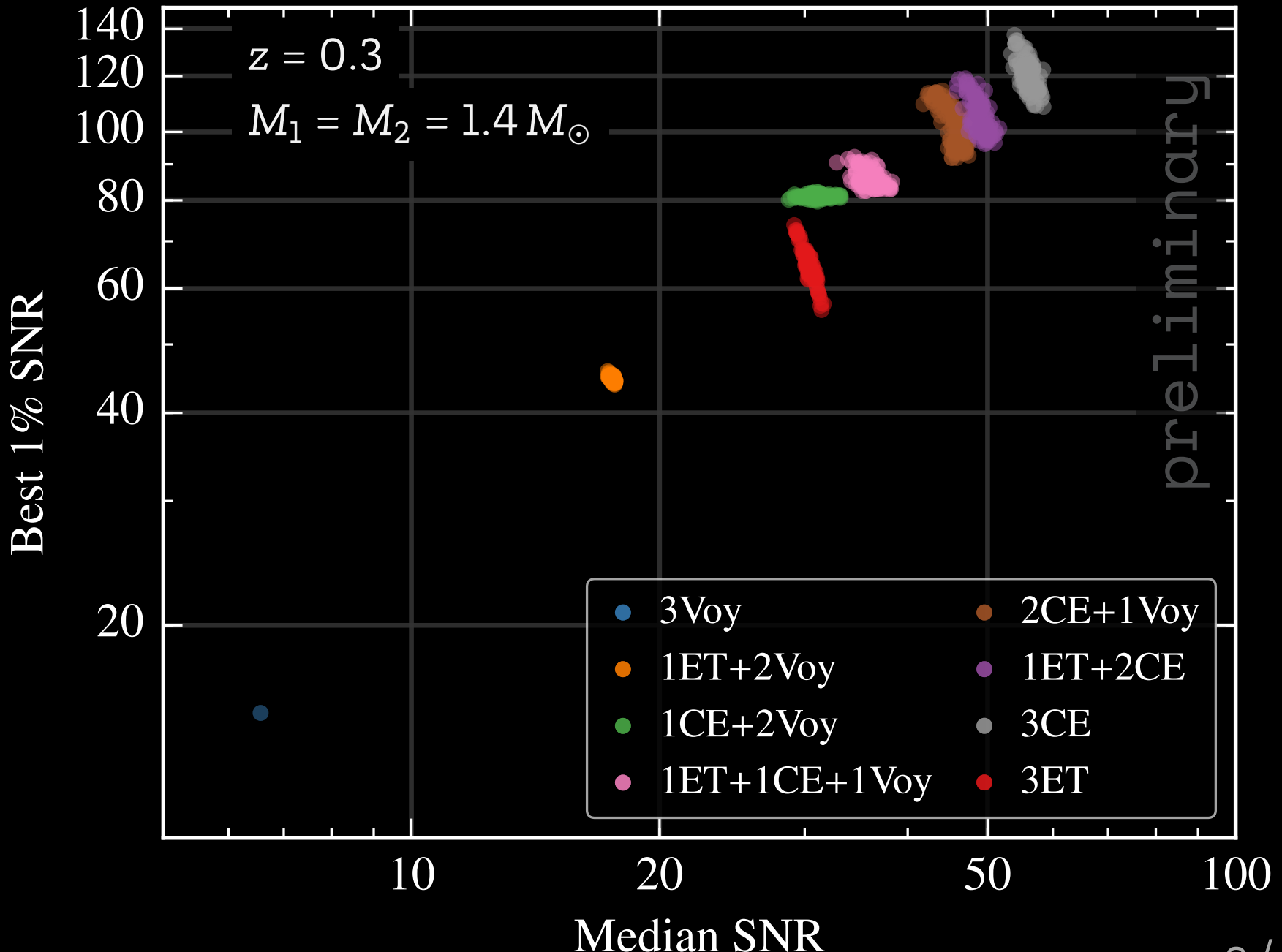
# Localization versus area



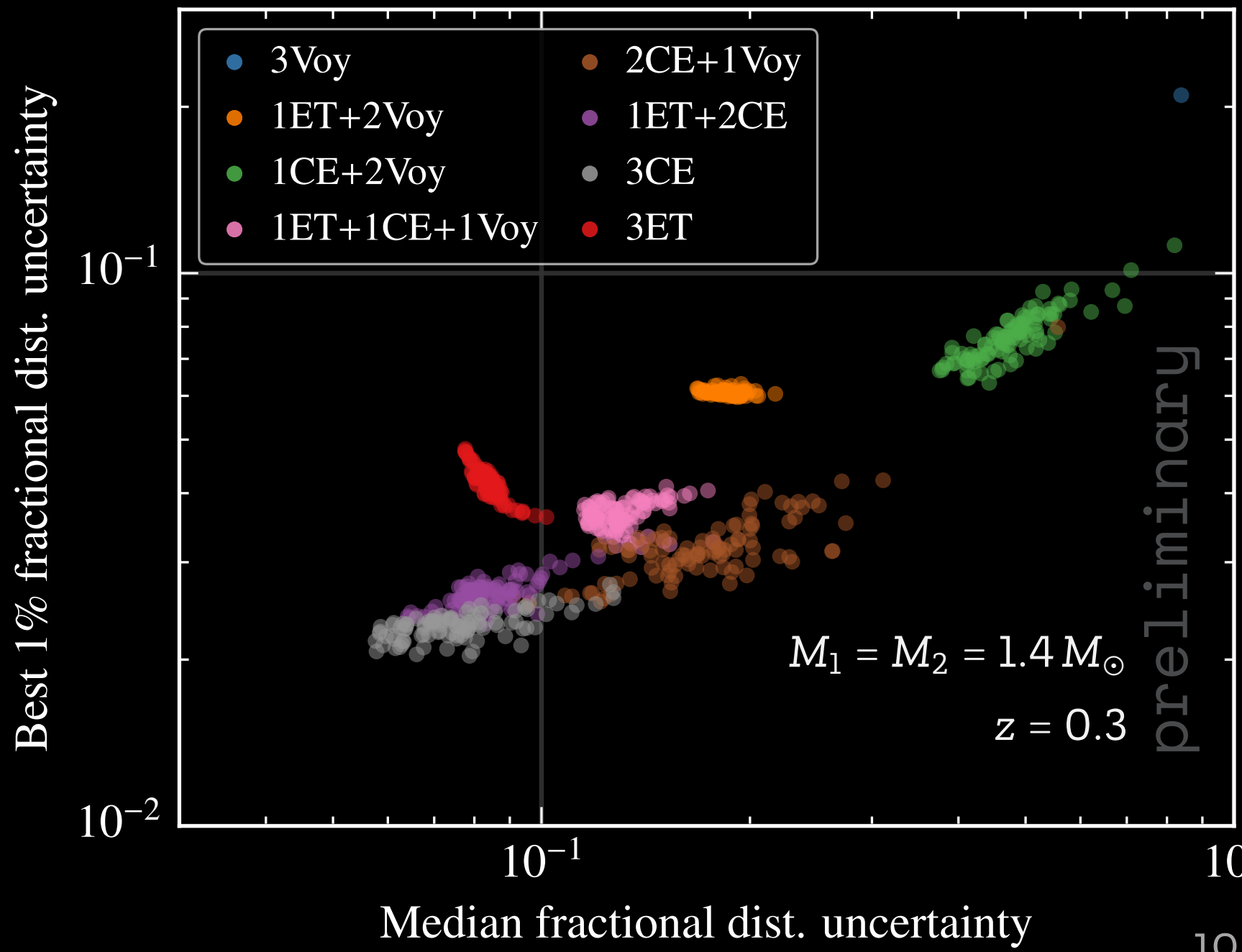
# Localization: median versus best



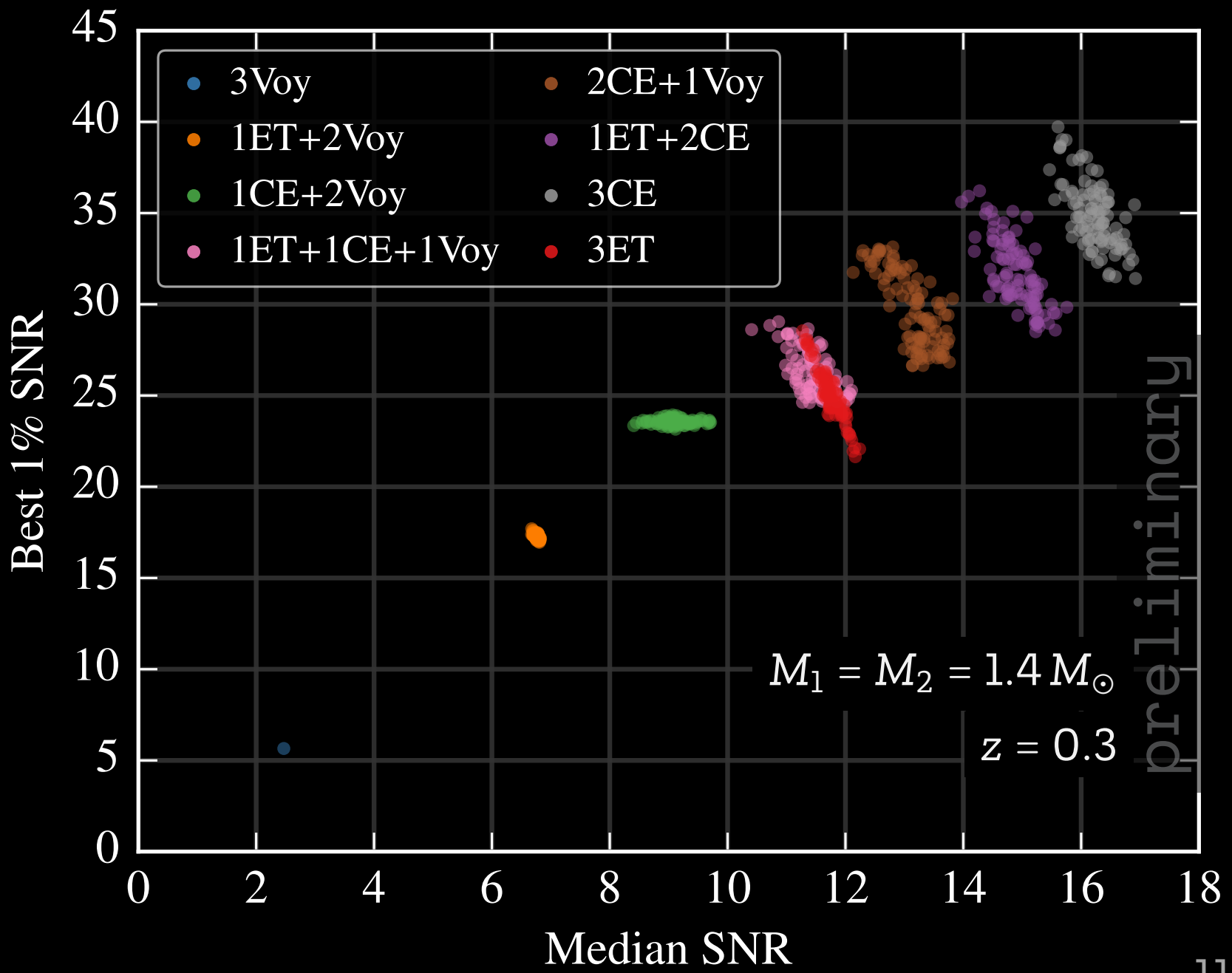
# Signal-to-noise ratio



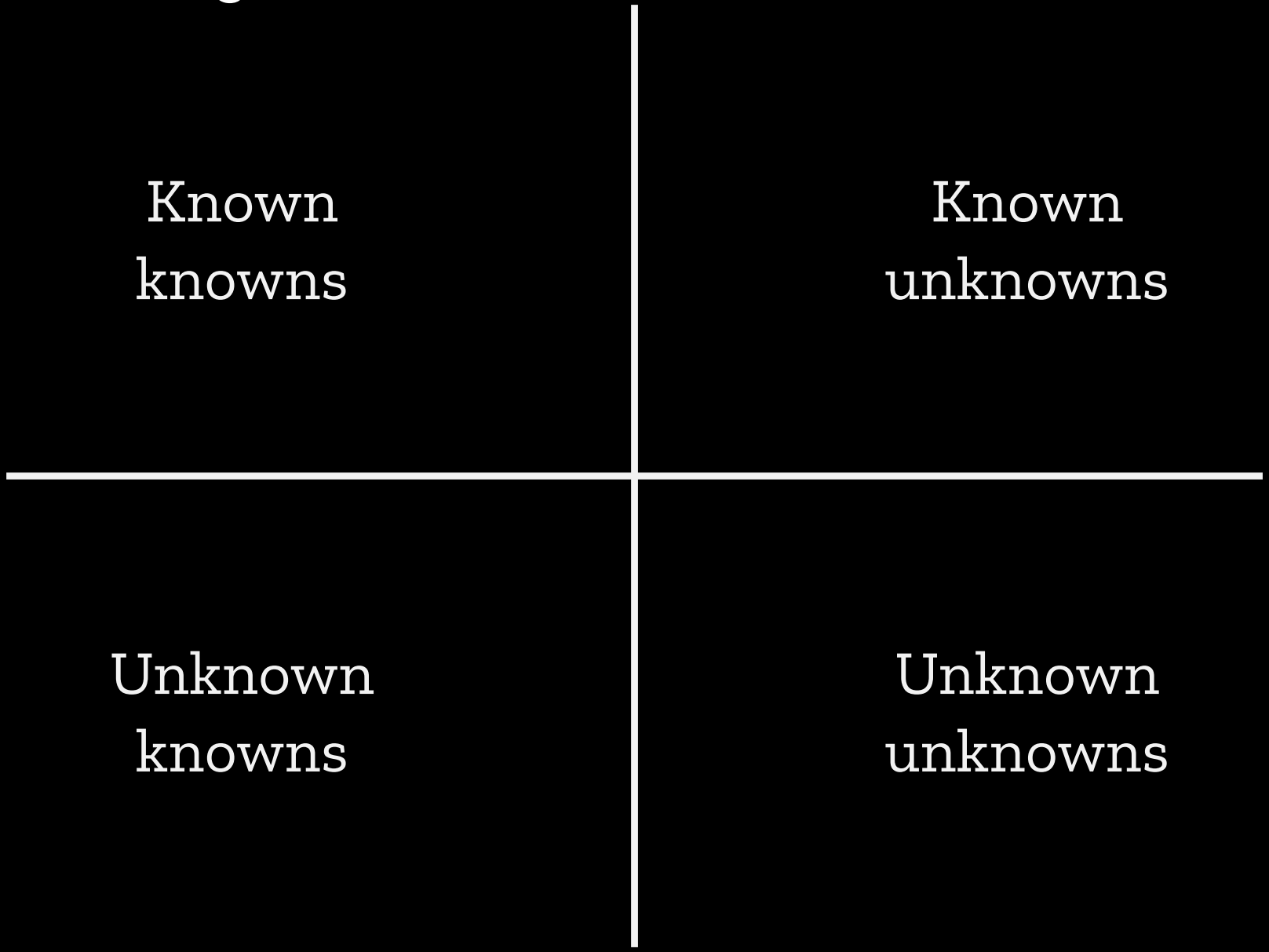
# Luminosity distance



# High-frequency SNR for unmodeled sources



# Metricating the unknown?



# Preliminary conclusions

It mostly doesn't matter what percentile events you optimize for

A 2G facility isn't a replacement for a 3G facility no matter how clever you are with your network

# References


[1] P. Raffai et al., "Optimal networks of future gravitational-wave telescopes", Classical and Quantum Gravity **30**, 155004 (2013).

[2] Y.-M. Hu et al., "Global optimization for future gravitational wave detector sites", Classical and Quantum Gravity **32**, 105010 (2015).

[3] S. Vitale et al., "Parameter estimation for binary black holes with networks of third-generation gravitational-wave detectors", Physical Review D **95**, 064052 (2017).

[4] S. Vitale et al., "Characterization of binary black holes by heterogeneous gravitational-wave networks", arXiv preprint arXiv:1804.07866 (2018).

# References (2)


[5] J. Mills et al., "Localization of binary mergers with gravitational-wave detectors of second and third generation", arXiv preprint arXiv:1708.00806 (2017).

[6] W. Zhao et al., "Localization accuracy of compact binary coalescences detected by the third-generation gravitational-wave detectors and implication for cosmology", Phys. Rev. D **97**, 064031 (2018).

[7] Y. Michimura et al., "Particle swarm optimization of the sensitivity of a cryogenic gravitational wave detector", Phys. Rev. D **97**, 122003 (2018).