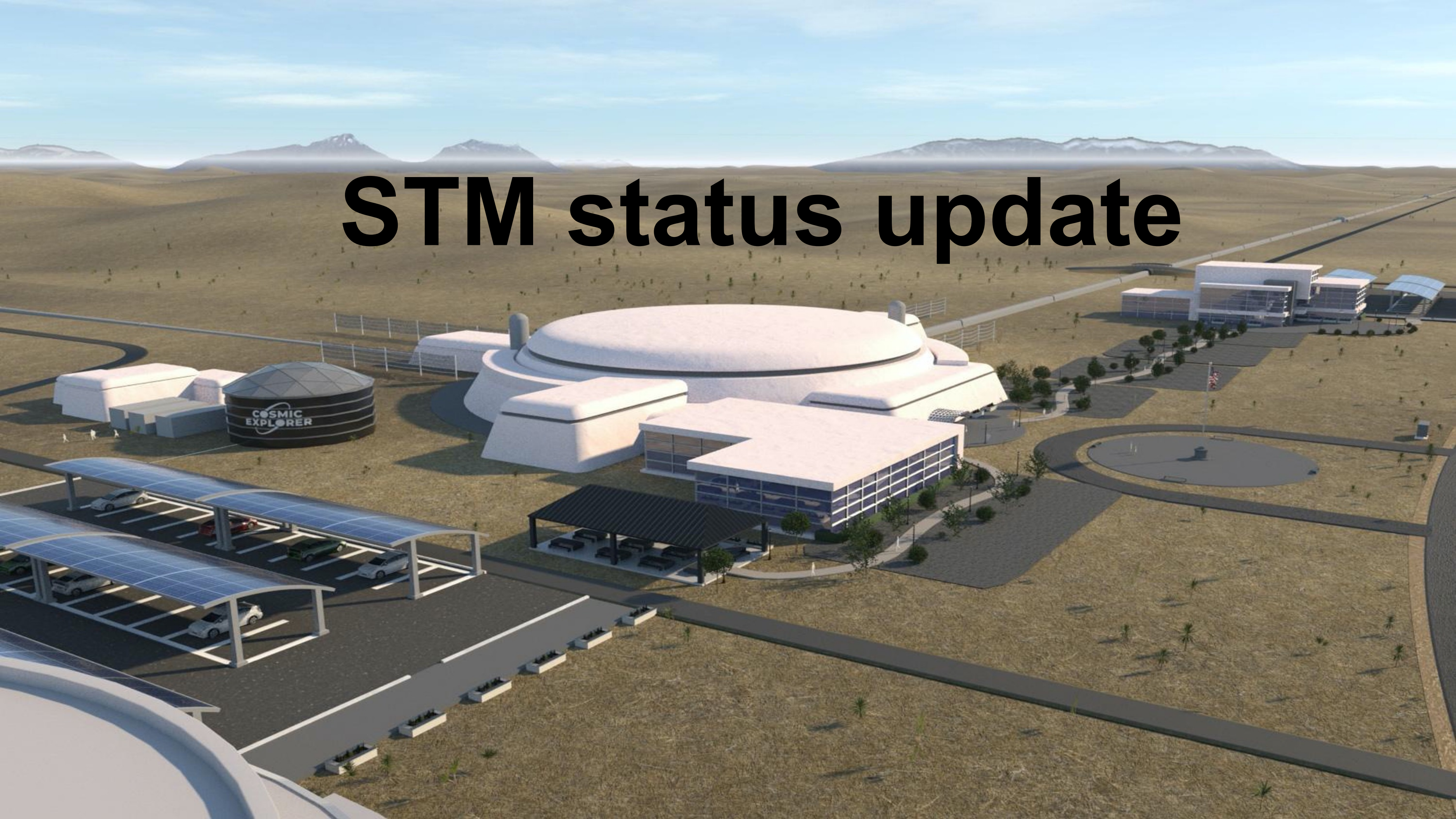
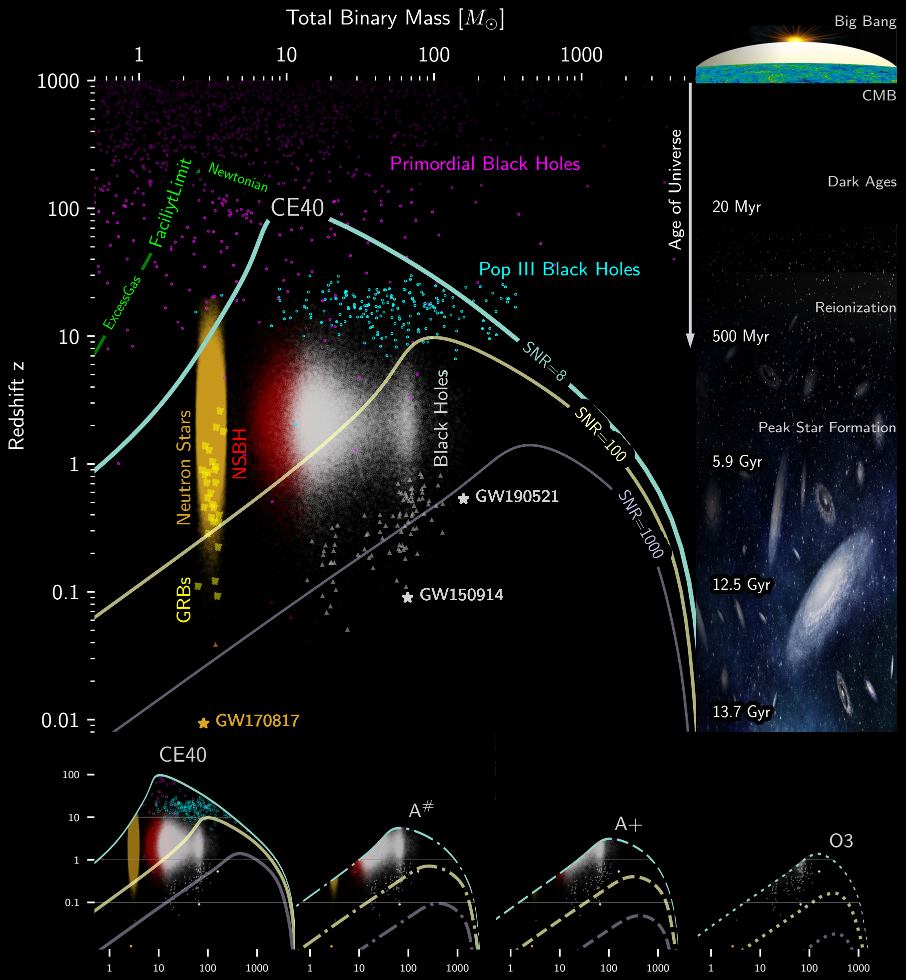
STM status update





Expect to detect BH mergers back to cosmic dawn and a large number of events involving NS with possible EM counterpart signals.

Question: How much science can we extract from these observations and to what extent does the answer depend on instrument design and the international network?

Motivates the STM effort.

What is the STM?

"Justify monetary requests with strategic, clearly stated/credible, science goals."

- **Science Goals**: From high-level strategy/vision documents.
- **Science Objectives**: The specific science questions we need to answer.
- **Measurement Objectives**: The specific measurements required.
- **Measurement Requirements**: What a measurement must include in terms of content, precision and quality in order to accomplish the measurement objectives.
- **Instrument Technology Requirements**: Identify technology critical for accomplishing the measurement requirements (including detector networks).
- **Data Products**: Define the output of each measurement (for example, a map or a spectrum), likelihood, Bayesian evidence, Bayes factor, etc.

§ 2.1 Black holes and Neutron Stars throughout the Universe
Exquisite characterization of BBH: $N_{\rm BBH}$/yr SNR > 100
Exquisite characterization of BNS: $N_{\rm BNS}$/yr SNR > 100
Illuminating Pop III remnants: $N_{\rm BBH}$/yr, $z > 10$ $\Delta z/z < 0.1$
BNS mass function to cosmic noon: $N_{\rm BNS}$/yr, $z > 1$ $\Delta z/z < 0.2$, $\Delta m_1/m_1 < 0.3$
Masses of IMBHs: $N_{\rm IMBBH}$/yr $\Delta m_1/m_1 < 0.2$ $z > 3$
Pinning down Primordial BHs: $N_{\rm BBH}$/yr, $z > 25$ $\Delta z/z < 0.2$
9500
480
360
81
880
28
17
0
5
§ 2.2 Multimessenger astrophysics and dynamics of dense matter
Multi-band EM counterparts: $N_{\rm BNS}$/yr, $z < 0.1$ $\Delta\Omega < 1{\rm deg}^2$
NS radius: $N_{\rm BNS}$/yr with $\Delta R_{\rm NS} < 100$ m
Tidal deformability: $N_{\rm BNS}$/yr with $\Delta\tilde{\Lambda}_{\rm NS} < 50$
BNS post-merger detections per 5 yrs
Mapping GRBs to progenitors: $N_{\rm BNS}$/yr, $z > 2$ $\Delta\Omega < 100{\rm deg}^2$
Localization at star-formation peak: $N_{\rm BNS}$/yr $0.1 < z < 2$ $\Delta\Omega < 10{\rm deg}^2$
71
740
3100
0.15
5
66,000
27,000
260
1
0
0 XG
HLA
1 XG
20LA
40LA
2 XG
20LET
40LET
4020A
3 XG
4020ET
§ 2.4 Fundamental Physics and Cosmology
Constraining graviton mass: $N_{\rm BNS}$/yr, $z > 5$
Bright siren cosmology: $N_{\rm BNS}$/yr $\Delta D_L/D_L < 0.1$ $\Delta\Omega < 10{\rm deg}^2$
Hubble constant $\Delta H_0/H_0$ in units of $0.01/x$
Dark siren cosmology: $N_{\rm BBH}$/yr $\Delta D_L/D_L < 0.1$ $\Delta\Omega < 1{\rm deg}^2$
BBH root sum sq. post-inspiral SNR
Lensed BNS merger events/yr
880
4800
$x = 1$
$x = 7.5$
69
6800
1900
11,000
110
14
1
0
§§ 2.3, 2.5 Dark Energy, Dark Matter and Novel Sources
Dist in Mpc to detectable axion clouds in 1 yr
Dark energy parameter: Δw_0 in units of $2/x$
Detection of dark matter assisted NS implosions: $N_{\rm BBH}$/yr
Number of detectable pulsars in 1 yr data
High-z formation channels: $N_{\rm BBH}$/yr, $z > 10$ $\Delta z/z < 0.2$, $\Delta m_1/m_1 < 0.2$
Sensitivity to $\Omega_{\rm GW}$ in units of $2\times10^{-10}/x$ in 1 yr, SNR=3
2.1
$x = 100$
$x = 1$
9700
1
21
230
$x = 110$
0.3

Working Groups

The STM effort is divided into 6 (more or less self-organizing) working groups:

- Compact binary populations (CBC)
- Neutron star equation of state (EOS)
- Cosmology (COS)
- Multimessenger astronomy (MMA)
- Testing GR (TGR)
- Dark matter (DM)

The STM team meets monthly with calls for each WG in between.

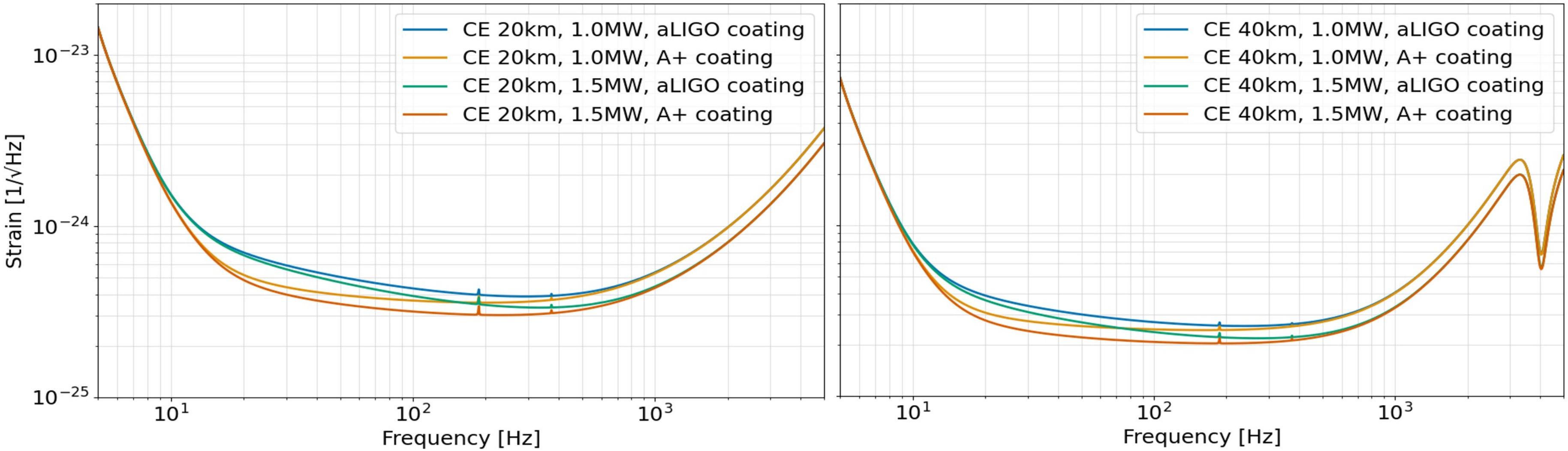
Also recognize the need for a better understanding of modelling/waveform systematics, but this is not part of the core STM.

Where are we?

In short… getting ready to carry out simulations.

- Each WG is preparing a "science summary" that motivates the simulations that will be carried out.
- Cover the significant "discovery potential" for xG instruments, but where we do not yet have "calculable" models.
- Initial effort will be based on Fisher analysis (calibrated with a full Bayesian analysis for some subset of models).
- The core effort will be based on population models (BBH, BNS and BHNS) developed by the CBC team and which can be used across the STM. Currently discussing overlap/input from other WGs.
- Aim to deliver results by end of 2025.

- CE40 vs CE20, each with 1MW or 1.5MW laser power, and aLIGO or A+ mirror coatings.
- Different low-frequency cut-offs: Conservative15 Hz (need to understand induced parameter systematics) and a set of lower cut-offs at 10, 7, and 5 Hz.
- International network including ET, with sensitivity as per the COBA study, and LIGO India.



Compact binary populations

- Measure individual binary parameters and the population properties. Mass, spin evolution and the redshift evolutions. Implications for star formation rate density models and merger rate estimates.
- Constraints on the high-redshift end of BH mass spectrum and implications for the first star remnants.
- Binaries with NS: binary NS and NSBH population properties. Equation of state inference from population (coordination with EoS group). Merger remnant and post-merger properties (coordination with MMA group).
- Input from astrophysicists on metallicity evolution, star formation rate density estimate, merger rate density etc.
- Binary formation and influence of astrophysical environment. Can we distinguish formation channels better using xG network?

NS equation of state

Minimal model that includes the main “observables” and which can be explored with existing waveform models.

Assume quasi-circular inspiral and include:

- chirp mass and symmetric mass ratio (leading to individual masses)
- spins (although high spins are debatable…)
- tidal deformability (mass-weighted, low-mass BHNS better?)
- the contribution from the dynamical f-mode tide
- (the main post-merger oscillation peak)

Planned simulations based on specific waveform model (IMRPhenomXHM_NRTidalv3) and commonly used “vanilla” EoS (SFHo).

Post-merger dynamics will be explored separately drawing on NR simulations from the CORE database (same EoS).

Cosmology

SCIENCE OBJECTIVES

Can we observe cosmological GW backgrounds from the early Universe?

Determine the energy budget of the stochastic GW background, with the focus on contributions from the very early phases of the evolution of the universe that are driven by particle physics at energies not accessible in colliders.

How strongly can ΛCDM parameters be constrained with GW observations?

Using various techniques utilizing GW observations for cosmological inference, individually and combined, how strongly can the LCDM parameters be constrained? How well can H(z) be constrained at low and high redshifts?

Early universe → Late universe

ANALYSES

Background simphony

We will perform a systematic assessment of the detectability of a cosmological background in the presence of a foreground from CBC as a function of its spectral shape.

Choir of sirens

Events in the CBC population can act as dark, bright, gray, Love, spectral, etc. sirens. Fisher error estimates for intrinsic and extrinsic GW parameters can be utilized to constrain ΛCDM parameters.

THINGS THAT REQUIRE SOME THOUGHT

1. What cosmological measurements that can be accomplished with XG observatories will set it apart from other probes (CMB, SNe, TRGB, etc.?)

1. What constraints can be placed on physical models via the detection of a cosmological background?

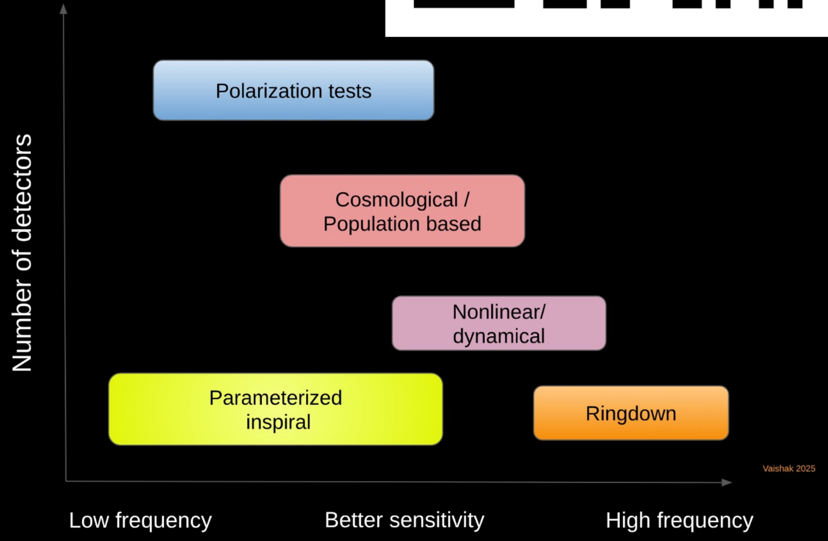
1. What are the optimal locations/orientations for the detectors, given the science goal? (Colocated and aligned for ORF, far away for sky localization)

Scan for STM Feedback

Tests of GR

- Minimal set of tests that highlight the importance of CE
- Strength in population based constraints.
- Highlight what can be done with CE network that other experiments cannot
- Availability of Bayesian stochastic sampling pipelines (expensive) for validation

1. Does general relativity correctly describe the dynamics of compact binary systems?
2. What are the polarization states of gravitational waves?
3. Does mass and spin angular momentum characterize isolated/perturbed astrophysical black holes?
4. What is the final state of black holes in binary mergers and how do they approach it?
5. Are cosmological observations consistent with general relativity?
6. What can GW observations say, if any, about QG?



Dark Matter

We need your feedback!

- Team Members
  - Violetta Sagun (v.sagun@soton.ac.uk)
  - Alex Nitz (ahnitz@syr.edu)
  - Sumit Kumar (s.kumar2@uu.nl)
  - **We can use your help!**
- Where are we?
  - Dark Matter Scenarios (lots of them)
    - WIMPs (Weakly Interacting Massive Particles)
    - Ultralight dark matter/Fuzzy dark matter
    - Macroscopic dark matter (MACHOs) /
    - Atomic DM (dark protons, dark electrons, etc.)
    - ….
  - Cosmic Explorer Observables -> (Modified EOS, unusual populations, direct detector observation)
- What are the major issues?
  - What are the most firm theoretical models? What are the potential uncertainties?
  - How do we set concrete science targets?

We welcome your feedback!

Scan for feedback

https://tinyurl.com/cestmfeedback