What we would like to achieve with the CE Science Traceability Matrix (STM) - instrument view -

CE Symposium Parallel Session
(Monday, June 30th, 2025 2.30-3.30pm)

SCIENCE TRACEABILITY MATRIX

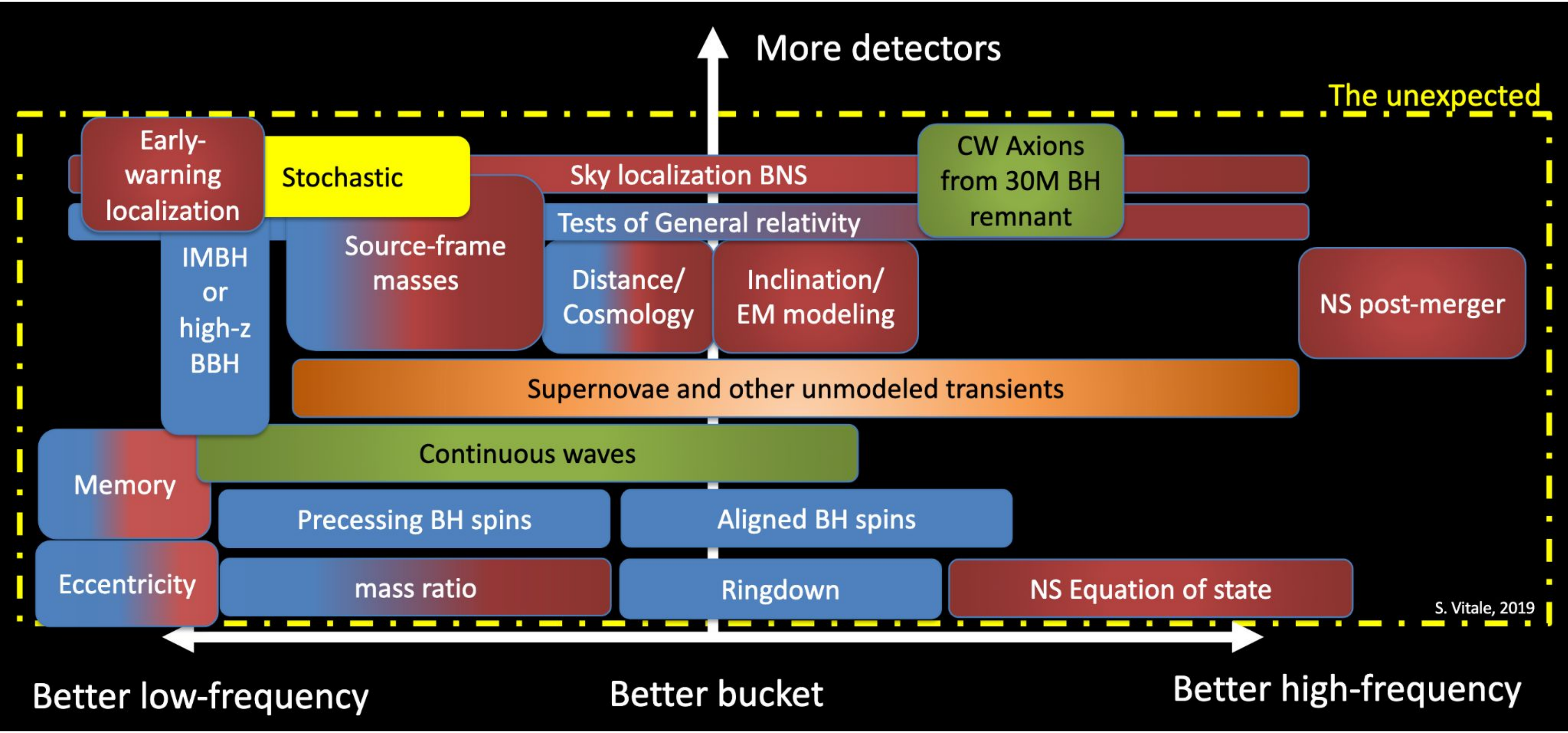
Science Goal	Science Objective	Key Observations	Measurement Requirements	Mirror and Instrument Requirements		
				Instrument	Property	Value
See the Dawn of Black Holes	**Observe progenitors of supermassive black holes at their seed stage at z=10**	Detection of black holes in z=10 galaxies down to a mass limit of M_{BH}=10,000 M_{Sun} over a volume with 10^4–10^7 potential host galaxies. §1.1.3, Appendix A.3	Surveys with flux limits (0.5–2 keV): • 1.6×10^{-19} erg/s/cm^2 over 1 deg^2 • 7×10^{-20} erg/s/cm^2 over 400 arcminutes^2	Mirror+ HDXI	Angular Resolution (HPD)	<1 arcseconds across the field
					Grasp @ 1 keV	~2 m^2 × 300 arcminutes^2
					Imager pixel size	0.33 arcseconds
Reveal Invisible Drivers of Galaxy and Structure Formation	**Determine the state of diffuse baryons in galactic halos to guide the galaxy formation models**	Direct imaging observations of 15 low-z galaxies with M_{tot}~3×10^{12} M_{Sun}. §2.1.4, Appendix A.5	Reach 10% accuracy for derived thermodynamic parameters of hot gas at 0.5 r_{200}	Mirror+ HDXI	Effective Area @1 keV	2 m^2
					Field of View	10 arcminute radius
					Spectral Resolution @1 keV	60 eV (FWHM)
					Particle Background @0.5-2 keV	< 0.0005 cnt/s/arcmin^2/keV
		Characterization of hot halos beyond the virial radius in ~30 galaxies with mass $10^{11.5}$–$10^{12.5}$ M_{sun} at z=0-1. §2.1.5, Appendix A.5	Observe 80 bright AGN sight lines to reach the sensitivity of 1 mÅ for Ovii and Oviii absorption lines	XGS	Spectral Resolving Power	5,000
					Effective Area at 0.45-0.7 keV	4,000 cm^2
	Establish the energetics, physics, and the impact of energy feedback on galactic scales	Spatially and spectrally resolve the structure of starburst-driven winds in low-redshift galaxies. §2.2	Measure the outflow velocity profile in 20 galaxies with 100 km/s accuracy, and derive the momentum and energy flux	LXM / Ultra High Resolution Array	Spectrometer Pixel Size	1 arcsecond
					Energy Resolution @0.2-0.75 keV	0.3 eV (FWHM)
					Spectrometer Subarray Size	1 arcminute × 1 arcminute
		Determine the effects of AGN energy feedback on ISM, and determine the physical state of gas near the SMBH sphere of influence in nearby galaxies. §2	In 30 nearby galaxies, resolve extended emission line regions, AGN inflated bubbles, and characterize the thermodynamic state of gas with 10% precision at or close to the Bondi radius from the central black hole	Mirror + LXM / Enhanced Main Array	On-axis Angular Resolution	0.5 arcseconds (HPD)
					Spectrometer Pixel Size	0.5 arcseconds
					Energy Resolution @0.6-7 keV	3 eV
					Spectrometer Subarray Size	1 arcminute × 1 arcminute
Unveil the Energetic Side of Stellar Evolution and Stellar Ecosystems	**Constrain SN explosion physics, the origin of elements, and a relation between SN activity and local environment**	Survey of young SNR in Local Group galaxies. §3.3	Measure spatial structure of SNRs in spectral lines of individual elements (e.g. Fe-Kα), and in non-thermal emission	LXM / Main Array	Spectrometer Pixel Size	1 arcsecond
					Spectrometer Field of View	5 arcminutes × 5 arcminutes
					Energy Resolution @0.6-7 keV	3 eV (FWHM)
					Effective Area @6 keV	1,000 cm^2

Mission Functional Requirements

Operate and survive in the science orbit, with a minimum observing efficiency of 85%, for the duration of the 5-year mission	Accommodate payload in the Launch Vehicle	Provide data collection that is sufficient for uninterrupted observations by all science instruments	Provide pointing attitude control and knowledge consistent with sub-arcsecond imaging, as well as stability consistent with a 1 arcminute FoV

Table 5.2

LIGO-G1900660 (Salvo Vitale)



STM work now ongoing for Cosmic Explorer (Nils, Sathya et al, see plenary)

- Goal is to connect major science objectives with detector and network capabilities, modeled on NASA missions
- What is the “right” parameter space for detector and network options?

Networks

- CE 40km (4 options)
- CE 20km (4 options)
- ET: Δ or 2L
- LIGO India (in A# configuration)

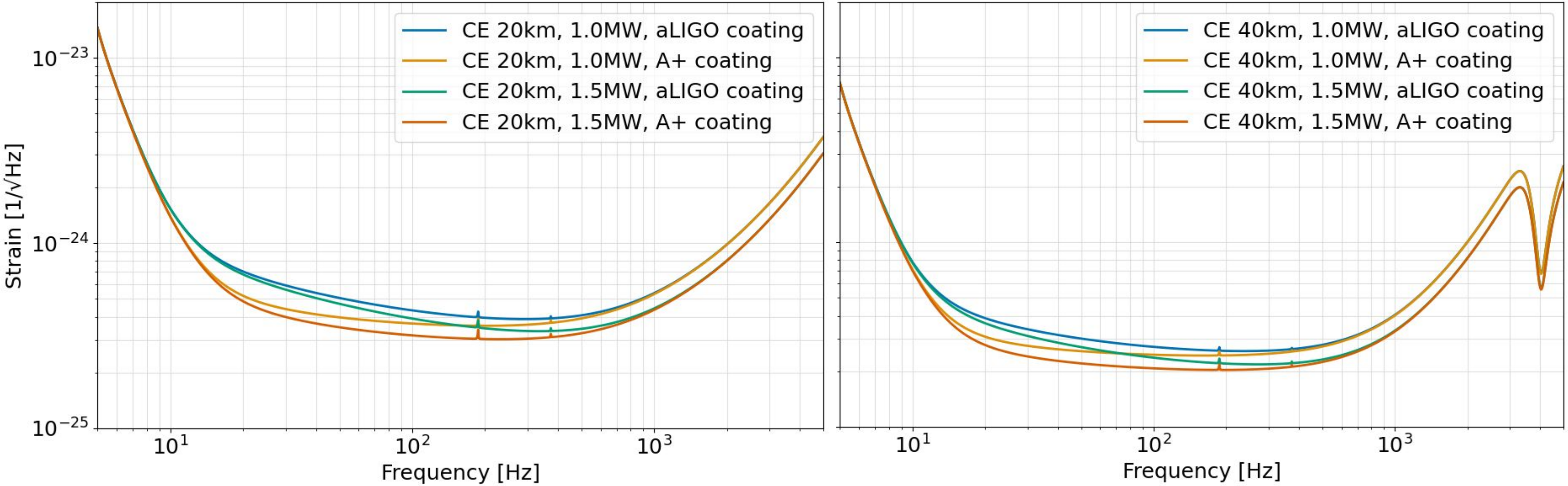
- Work already done to prepare for the nextGen MPSAC committee

- Here there are plausible “key observations” evaluated in the context of different networks

- Next step is to study how they change given different CE curves, for a fixed network.

Figure 4: Polar histograms (linear scale) showing how CE can accomplish the key science goals discussed in §1. Observatory networks are as in Table 2. Broadly, these histograms show that CE in its reference design, operating with at least one 4 km LIGO A♯ detector, will achieve the key science goals in §1, and that its scientific output would be further enhanced as part of an international network. *Top Left:* An XG network is critical to making high-fidelity observations (SNR > 100) of BH and NS populations, including primordial and Population III BBHs, while accurately measuring their masses, redshifts, and locations in the sky. *Top Right:* The HLA network cannot facilitate the electromagnetic follow-up of mergers at the highest redshifts accessible to the best telescopes while an XG network will routinely provide alerts to such mergers. XG observatories can make exquisite measurements of the radius of NSs and their tidal deformability, and detect post-merger signals from merger remnants. *Bottom left:* Precision tests of GR are enabled by extremely high-fidelity events (SNR > 1000), and also by combining data from thousands of lower-SNR events, producing root-sum-square SNR > 10 000 in the post-inspiral phase of BBHs. Additionally, thousands of BNS and BBH detections with accurate measurements of the distance and sky-localization facilitate precision cosmology and a few hundred strongly lensed events would provide fundamental probes of GWs and cosmography. *Bottom right:* The XG network has abundant discovery potential with the ability to measure the dark energy equation of state parameter w_0 (and its variation with redshift [164]), observe weak and rare signals (e.g., pulsars), speculative sources (e.g., BNSs converted to BBHs due to accumulation of dark matter), primordial backgrounds and an opportunity to discover physics beyond the Standard Model (e.g. axion clouds).

CE detector sensitivity options for STM study



- 1 MW or 1.5 MW power
- aLIGO coating or A+ coating
- Different low frequency cut-offs?

STM in Cosmic Explorer language

Agency Mission	Science goal	Science objective	Key Observations	Key Performance Parameters	Observatory System Requirements		
					Subsystem	Property	Value

Cosmic Explorer Key Performance Parameters (KPPs)

Parameters that describe the scientific potential of a Cosmic Explorer observatory, focusing on high-level parameters that represent the quality of the product

Are these all of the important parameters?

Scope (WBS)	Parameter	Threshold KPP	Objective KPP
Scientific Equipment			
These are based on the sensitivity and duty-cycle expected given the detector hardware delivered to operations.	low-frequeny sensitivity	BBH range	Better range
	mid-frequency sensitivity	max 100-500Hz sensitivity	lower max sensitivity
	high-frequency sensitivity	max 500Hz to 2kHz (sensitivity/f)	lower max noise
	observation duty-cycle	70%	90%
	alert latency	30s	5s
	data distribution capacity	10 users/day	100 users/day

STM in Cosmic Explorer language

Agency Mission	Science goal	Science objective	Key Observations	Key Performance Parameters	Observatory System Requirements		
					Subsystem	Property	Value
			BNS post-merger	High-freq sens	SQZ PSL	Sqz level Power in the arms	10 dB 1.5 MW

Open Discussion

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