NASA GW-EM Task Force Summary

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GW-EM Task Force Goals and Implementation

- Focusing on n**eutron star mergers** from by ground-based high-frequency gravitational wave network (LIGO, Virgo, KAGRA)
  - Develop **protocol** for optimized GW-EM observations, operations, R&A in current and in-development NASA missions
  - **Adapt to increased rates** of sources after ~2025 GW network upgrade A+
  - Evaluate how **coordination/communication** could be improved
  - Identify **capabilities** needed for **Future Mission**
- Implementation
  - NASA Mission Questionnaire & Follow-up Discussions
  - GW-EM Community Survey
  - Future Mission Capabilities: Source Rates and Detectability Analysis
- Topics
  - Observation Strategy, Mission Resources, Use of NASA facilities, Multiwavelength Coordination, Observing Plan Coordination, Data Analysis and Theory Proposals, Joint observing programs, Transient Communication Systems, Proprietary Periods, Archives, Diversity
- Full final report will be released by the end of January 2020

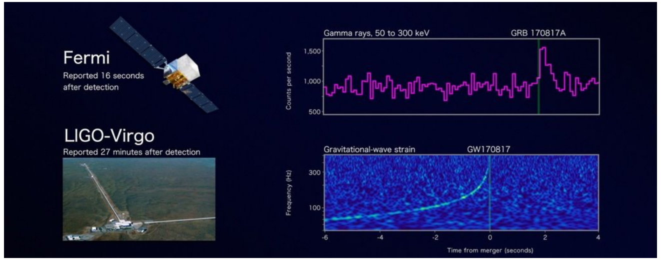
GW-EM Task Force Executive Summary

- **NASA missions played a critical role** in the discovery and characterization of the first binary neutron star merger (GW170817)
- In the near future, the **balanced mission portfolio is well-positioned** to continue to make major contributions to EM counterparts of gravitational-wave sources. **Enhanced target-of-opportunity capabilities, improved communication and coordination, and improvements to Guest Investigator/Observer and Research and Analysis programs**, could further augment the science return.
- **By the mid-2020's, NASA runs a serious risk of lacking critical observational capabilities for supporting gravitational-wave science goals**. Current workhorse facilities (*Fermi, Swift, Chandra, HST*) are well past design lifetimes and lack suitable replacements. In addition, **new capabilities (wide-field UV imaging, improved sensitivity at high energies)** are needed to realize the full scientific potential of gravitational-wave detectors.

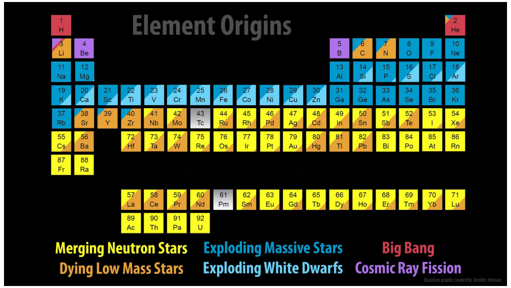
Science Enabled from GW170817

- Fundamental physics
  - Speed of gravity
  - Hubble Constant
  - Neutron Star Equation of State
- Production of Heavy Elements
  - UV kilonova
  - IR kilonova
- Relativistic Jet Formation and Structure
  - Origin of short GRBs
  - Off-axis structured jet afterglow
- Host Galaxy
  - Progenitor Age and Formation Channels

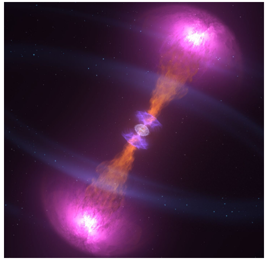
- Additional progress on all topics requires statistics from a population of GW-EM counterparts



Credit: NASA SVS

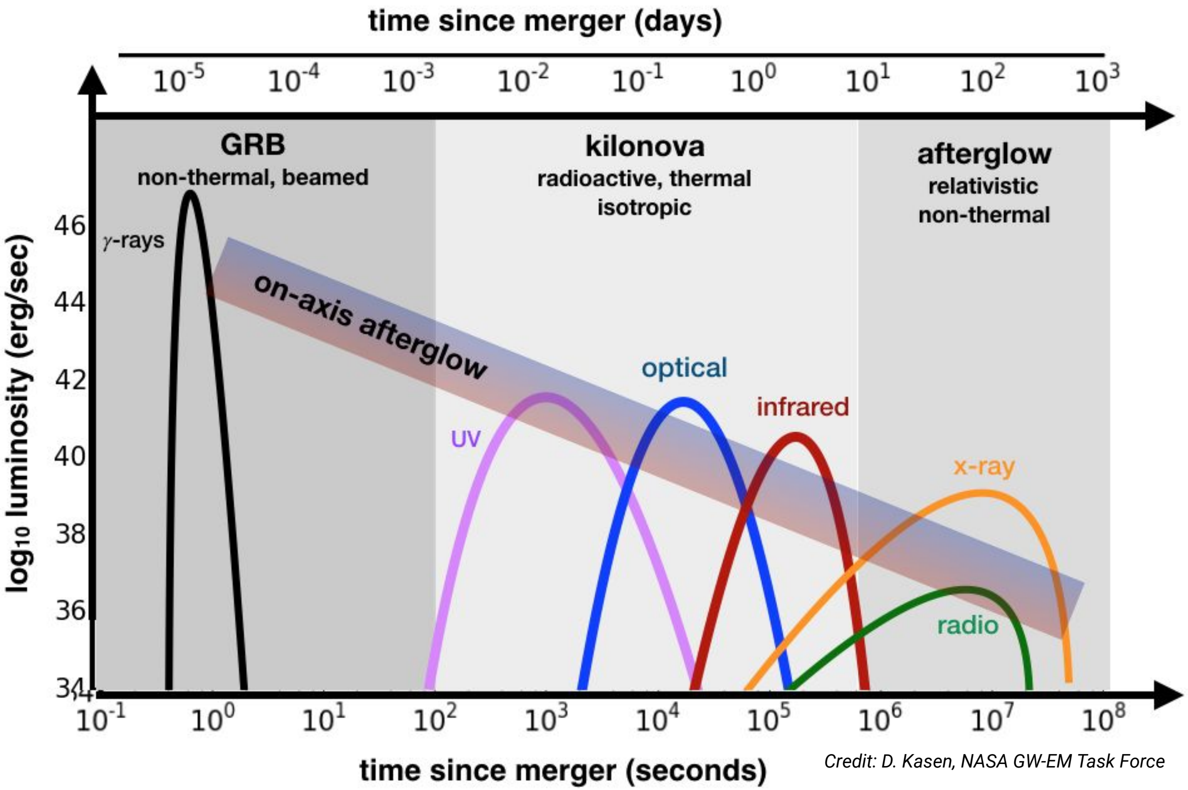


Credit: Jennifer Johnson/SDSS / CC BY 2.0 (modified)

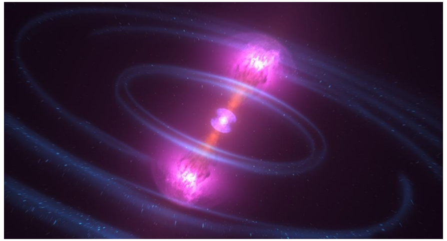


Credit: NASA SVS

Electromagnetic (EM) Counterparts Overview



Credit: D. Kasen, NASA GW-EM Task Force



- Gamma-ray burst (GRB) and On-Axis Afterglow: Relativistic jet viewed within cone
- Kilonova: Radioactive glow from heavy elements, isotropic
- Off-Axis Afterglow: Relativistic jet viewed after lateral spreading
- **Panchromatic phenomenon with a variety of time scales**

Task Force Key Finding #1: The Past

The joint discovery of gravitational waves and electromagnetic radiation from the binary neutron star merger GW170817 was a watershed moment for astrophysics. ***NASA missions played a critical role in this discovery****, from constraining the speed of gravity, to determining the site of heavy (r-process) element formation, to furthering our understanding of the formation and structure of relativistic jets.*

Key open questions explored by joint GW-EM observations of compact binary mergers

- Can binary neutron star mergers reproduce the relative and total abundances of heavy (r-process) elements?
- What is the current expansion rate of the Universe (Hubble constant)?
- What conditions are necessary to produce relativistic jets, and what is their composition/structure?
- What is the equation of state of dense nuclear matter?
- Do black hole - neutron star and binary black hole mergers produce electromagnetic signals?

GW Network Landscape

Anticipated improvements:

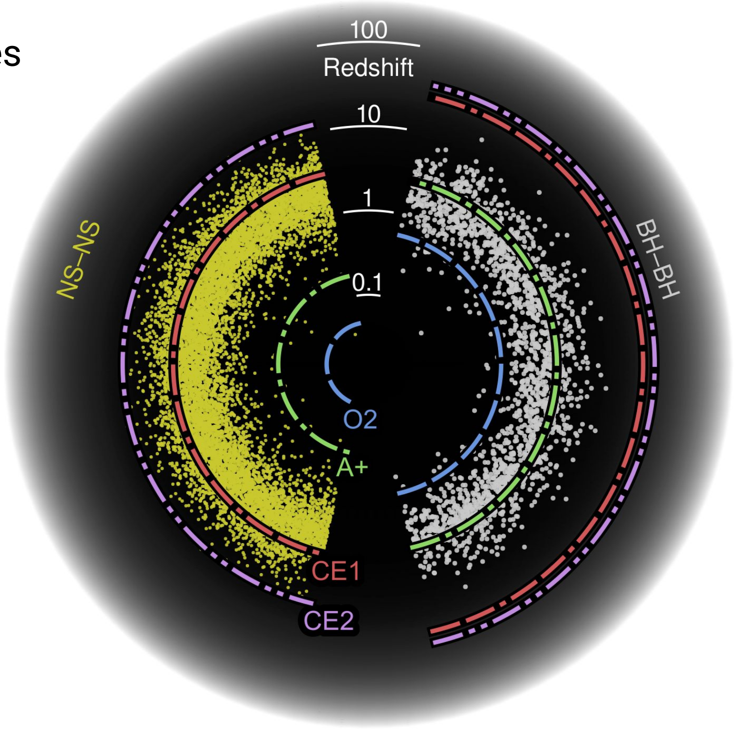
More GW detectors
Increased GW sensitivity

➡

Improved GW localizations
Increased GW detection rates
Increased distance horizon

Observing Run	**Timescale**	**BNS Rate (yr^{-1})**	**BNS Range (Mpc)**	**Redshift**
O1: LIGO	2015-2016	0.05-1	80	0.02
O2: LIGO/Virgo	2017-2018	0.2-4.5	100 / 30	0.02
O3: LIGO/Virgo	2019-2020	0-13	110-130 / 50 / 8-25	0.03
O4: LIGO/ Virgo/KAGRA	2021-2023	0.6-62	160-190 / 90-120	0.04
O5 (A+): LIGO/ Virgo/KAGRA/India	**late-2024+**	**10-200 / >30**	**330 / 150-260 / 130+**	**0.07**
Voyager	~2030?	>daily	1000	0.4
Cosmic Explorer 1	2035-2040	>hourly	>10,000	1.4
Cosmic Explorer 2	~2045	>hourly	All	10

Funded, Not yet Funded



Reitze et al., arXiv: 1903.04615

Data:
LIGO, Virgo, and Kagra Collaborations et al. arXiv:1304.0670 (updated 9/2019)
Burns 2019, arXiv:1909.06085
Leo Singer, private communication, updated version of Observing Scenarios, LVC, in-prep

Task Force Key Finding #2: The Present

In the present/near-future (O3+O4 Observing Runs, 2019-2023), NASA is well-positioned to capitalize on the exciting scientific opportunities in (high-frequency) gravitational wave astronomy. As highlighted in the 2019 Astrophysics Senior Review of Operating Missions, the portfolio provides a suite of capabilities that is "greater than the sum of its parts", and will contribute significantly to the major questions posed above. The science return in this area from currently operating and approved (i.e., in development) missions could be maximized by: a) ***enhanced target-of-opportunity capabilities****; b)* ***improved communication and coordination****; and c)* ***adjustments to GO/GI and R&A programs****.*

Enhance ToO capabilities of current and planned missions

Given growing community need, increased number of events, and technical limitations to decrease fastest response times, (a) ***increasing number of fast ToOs*** *and (b)* ***ensuring ToO capability in planned*** *missions should be top priorities.*

Mission	Current or planned ToO capability?	Fastest Response	Number of fastest response ToOs in latest cycle	Limitations to increasing number of fast-response ToOs
HST	Y	<36 hr	1-2	Technical feasibility, 24/7 on-call staff for responding to ToOs
Chandra	Y	<5 days	8 GO + 4 DDT	Technical limitations leading to difficult scheduling
Swift	Y	<1 hr	Not Limited	Ground station contacts
NuSTAR	Y	<48 hr	500 ksec	Operations funding (lack of 24/7 on-call staff)
NICER	Y	<1 hr	Not Limited	Tools such as web visibility calculator
JWST	Y	<48 hr	8	Scheduling, technical
WFIRST	N	< 2 weeks	N/A	Funding

GW-EM Science Benefits from Joint Observing Opportunities

Joint observing opportunities (using most recent calls for proposals as of November 2019):

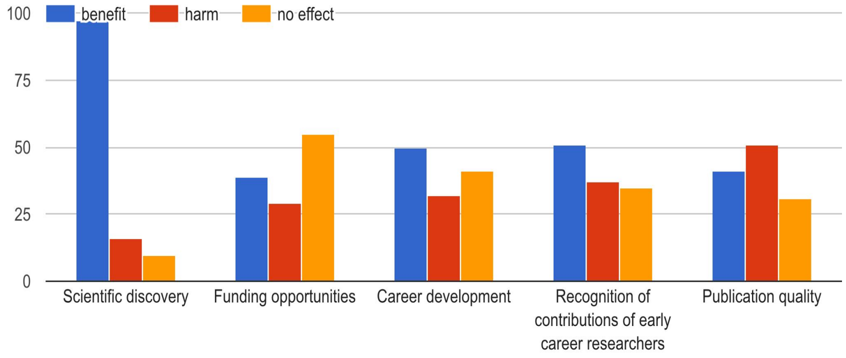
	Primary Program							
Joint Facility	***HST***	***Chandra***	***XMM***	***Swift***	***NuSTAR***	***Fermi***	***TESS***	***NICER***
HST		✓	✓					
Chandra	✓		✓					
XMM	✓	✓			✓			
Swift		✓	✓		✓		✓	
NuSTAR		✓	✓	✓				✓
Fermi								
TESS	✓							
NICER					✓			
NOAO	✓	✓				✓		
NRAO	✓	✓	✓	✓		✓		
INTEGRAL			✓			✓		
VLT			✓					
VERITAS						✓		
MAGIC			✓					
H.E.S.S.			✓					

- Maintaining a public updated list of **joint observing opportunities**
- NASA pursuing **additional joint programs** where scientifically relevant
- In addition to single agency calls, a **joint funding program** with the NSF (LIGO, LSST, etc.) would open new opportunities for novel multi-messenger programs.

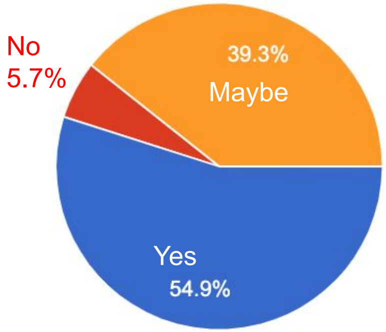
Proposals and Proprietary Periods

- Community survey respondents **were positive about allowing multiple co-PIs** (as HST and some NSF programs do), which could help early career scientists get recognition as PIs and facilitate collaboration among groups.
- Most community survey respondents **favored shorter (< 1 month) proprietary periods**, believing this would enhance science discovery and benefit early career scientists

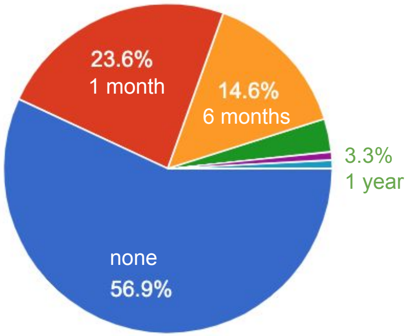
Community Survey: *How would zero proprietary periods affect the following?*



Community Survey: *Will allowing multiple co-PI's benefit early career researchers?*

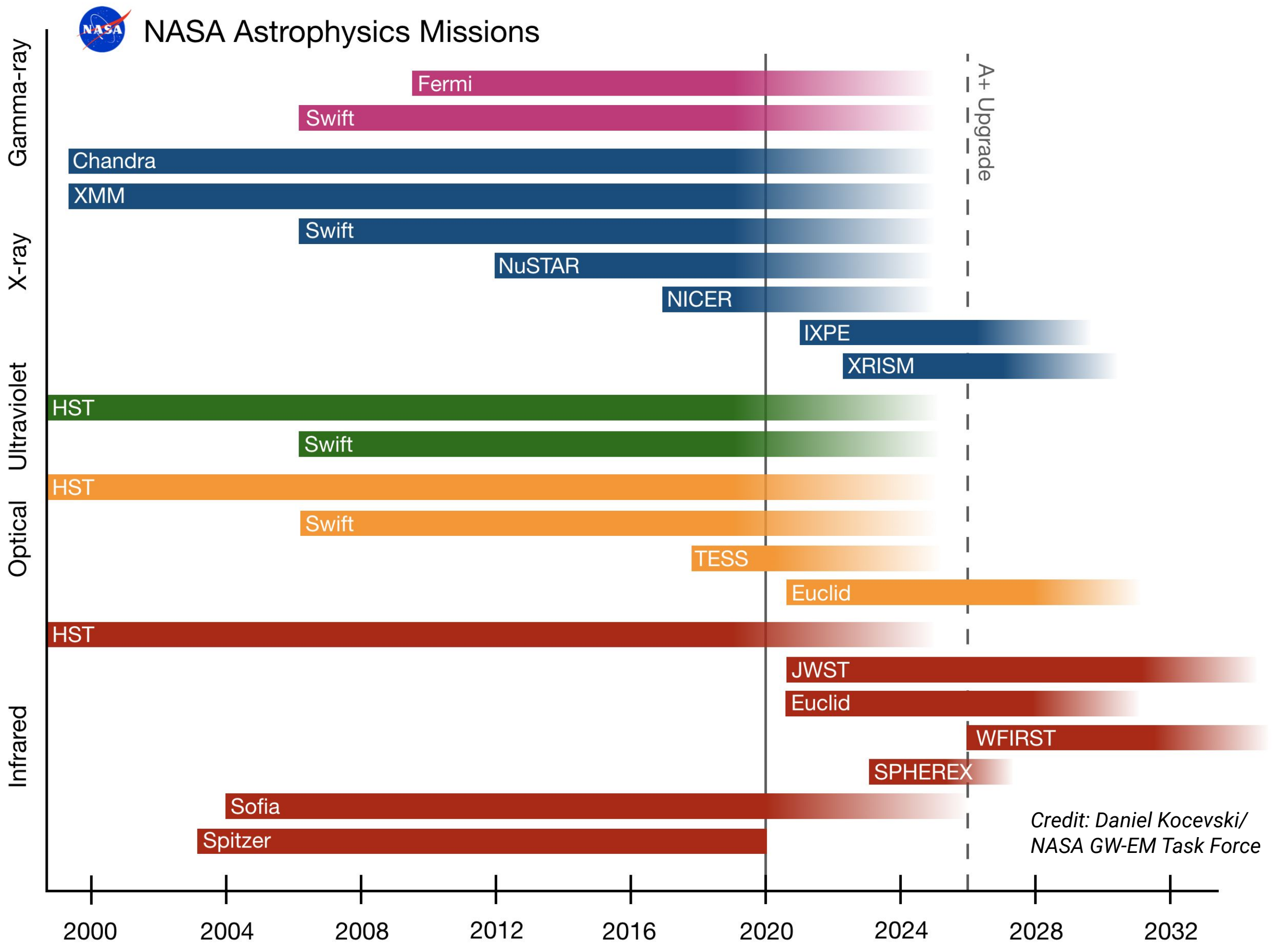


Community Survey: *What proprietary period for NASA missions would be most appropriate for GW-EM observations?*



Task Force Key Finding #3: The Future

*For the **A+ era and beyond** (> 2025), NASA runs a serious risk of lacking critical observational capabilities for achieving the science goals described above. Not only are multiple gaps in the current suite of instrumentation not planned to be addressed, but presently available capabilities are not slated to be replaced when older missions are retired or become inoperable. **Continued operations** of the primary NASA GW-EM facilities (Fermi, Swift, Chandra, and HST) until suitable replacements are available would greatly benefit the science. **Critical new capabilities** in the NASA portfolio include **wide-field / rapid-response UV imaging** and **wide-field high-energy (gamma-ray and/or X-ray)** imaging. A commitment towards maintaining a balanced portfolio is critical to maximize scientific potential in the multi-messenger era.*

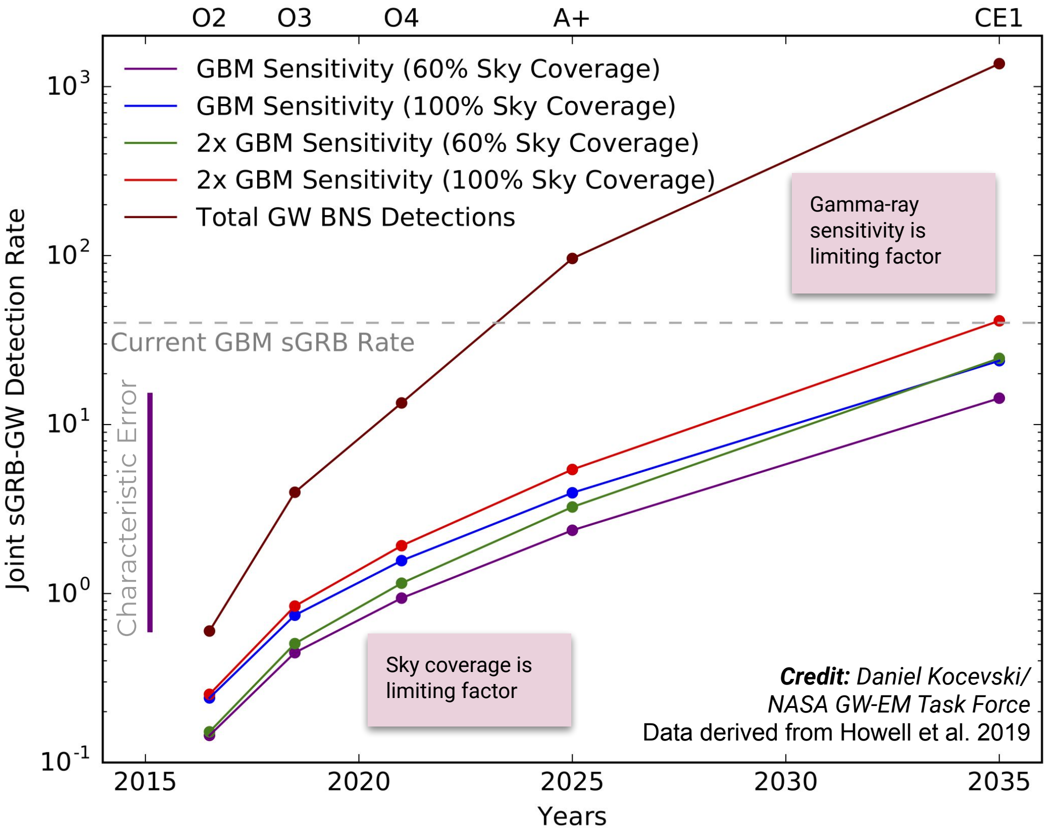


Credit: Daniel Kocevski/ NASA GW-EM Task Force

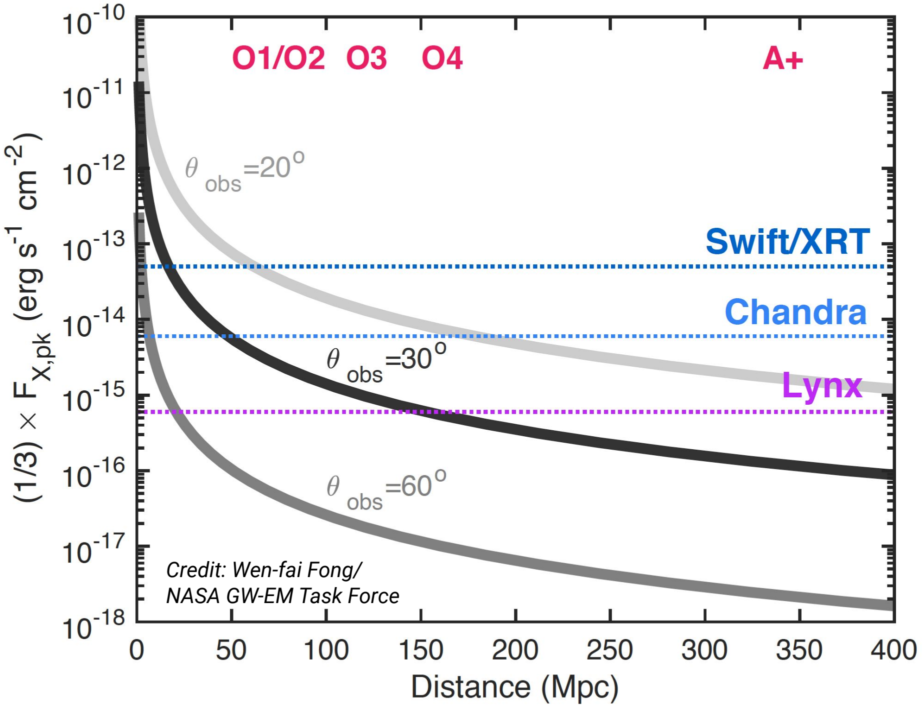
- Many current missions are well **past design lifetimes**
- Downside of a balanced mission portfolio is **little/no redundancy** in critical capabilities
- **No replacements** planned for multiple “workhorse” GW-EM facilities
- Future mission portfolio leaves **significant gaps** in capabilities (e.g. gamma-ray, UV)
- **Gaps** could **coincide** with dramatic increase with GW detector sensitivity
- CubeSats/SmallSats/MOOs are complementary, but do not replace capabilities of large missions

GW Counterparts: Gamma-ray Bursts

- Total BNS detections in GWs will grow by two orders of magnitude in the next decade
- Almost every detected sGRB will be accompanied by a GW detection by 2035-2050
- Increasing gamma-ray sky coverage is as important as increasing gamma-ray sensitivity to maximize future joint GW-sGRB detections
- Sub-threshold searches will be even more sensitive, but require continuous untriggered data be sent to the ground



GW Counterparts: X-ray Afterglows

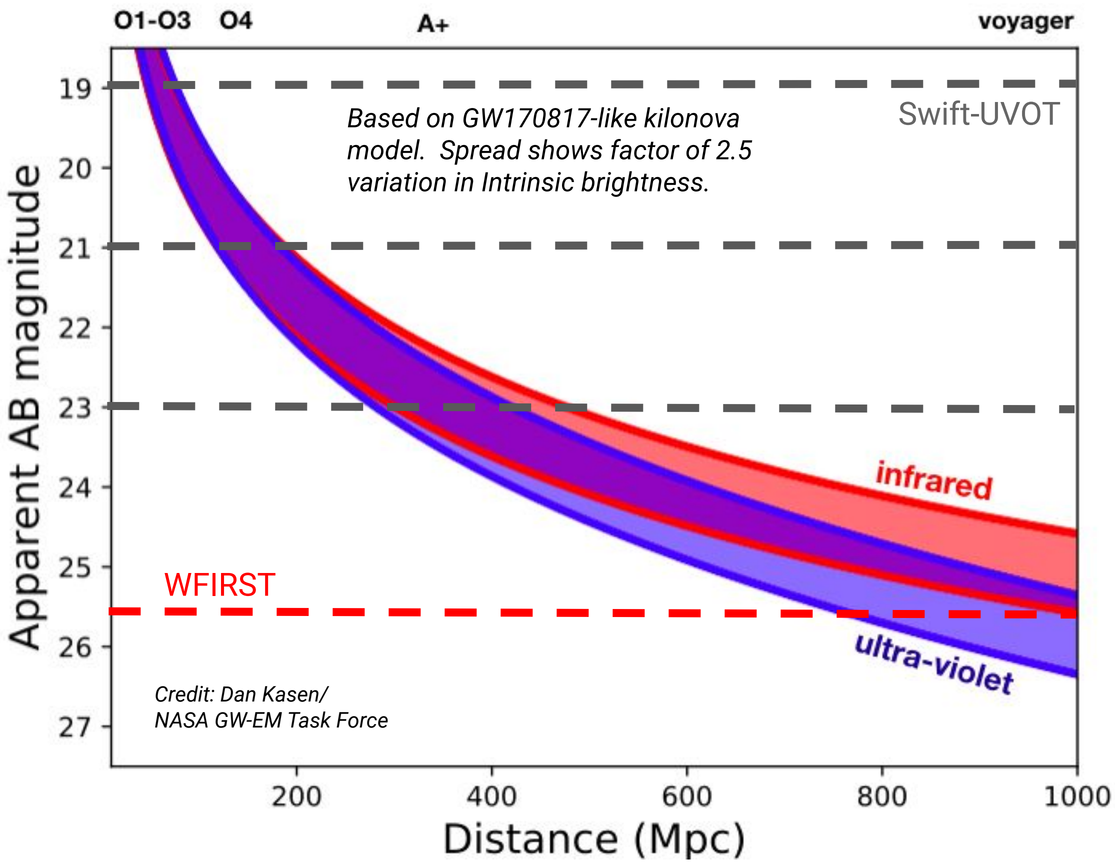


A conservative estimate of 3x below the peak flux has been used in these limiting calculations.

- For observer angles ≤30 degrees (40% of GW events and similar to GW170817), current NASA facilities are capable of detecting and characterizing X-ray afterglows through O4.

- Beyond O4, no current or planned X-ray mission has the sensitivity required to detect and characterize the X-ray counterparts to most NS mergers at observer angles >30 degrees.

GW Counterparts: Kilonovae



- UV peaks ~hours, optical peaks ~1 day, IR peaks ~few days
- Wide-field or tiling instruments ideal for discovery / Narrow-field, sensitive instruments best for characterization
- Swift/UVOT can tile ~1000 galaxies (~100 deg^2) to 19th magnitude in ~1 day
- O4 requires ~21 mag over ~100 deg^2 within a few hours
- A+ requires ~23 mag over ~50 deg^2 within a few hours
- WFIRST (0.3 deg^2 field of view) could follow-up identified counterparts, and could tile very well-localized GW detections

GW-EM Task Force Final Report

- Report will be made public in Jan 2020
- Includes many other topics
    - Mission specific findings
    - Coordination/Communication
    - R&A programs
    - Joint observing programs
    - Future Capabilities needed for GW-EM science in the next decade
- NASA missions will play a vital role in GW-EM science in the next decade
- Because of the multi-wavelength nature of GW-EM science, better cooperation between ground- and space-based facilities, improved communication and archives, and sufficient funding opportunities would improve the scientific return
- Investments in the next few years in missions designed for GW-EM science will make NASA at the forefront of discovery