Status of a Space-Based Gravitational-Wave Observatory in the U.S.

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Outline

- Where are we?
- Paths forward
- 2020 Decadal
- Beyond the 2020 Decadal
- What the GW community needs to do now

Where are we?

- The last 4 years have been turbulent and traumatic.
- I still believe that:

LISA, or something like it, is the best idea for a scientific measurement that I know of.

- The low frequency band of the GW spectrum promises revolutionary science.
- A LISA-like mission will have excellent scientific return for the investment.

Disclaimers

- This talk describes the programmatic situation in order to promote community action.
- It doesn't advocate a strategy.
- This is only a summary of the strategic situation.
- Agency plans are just that. Plans. Reality is usually different.
  - We tend to believe them, despite history.
- Agency plans are effectively the most optimistic possibility.
- We are unlikely to know our future with much certainty.

Recent events (US perspective)

- LISA got ranked third among 'large' space projects in the 2010 decadal survey.
- The LISA Project was terminated when NASA could not afford to participate in L1.
- NGO did not get selected for L1.
- NGO did not get selected for L2.
- The 'Gravitational Universe' science theme got selected for L3.
- LPF has been making significant progress towards launch in 2015.

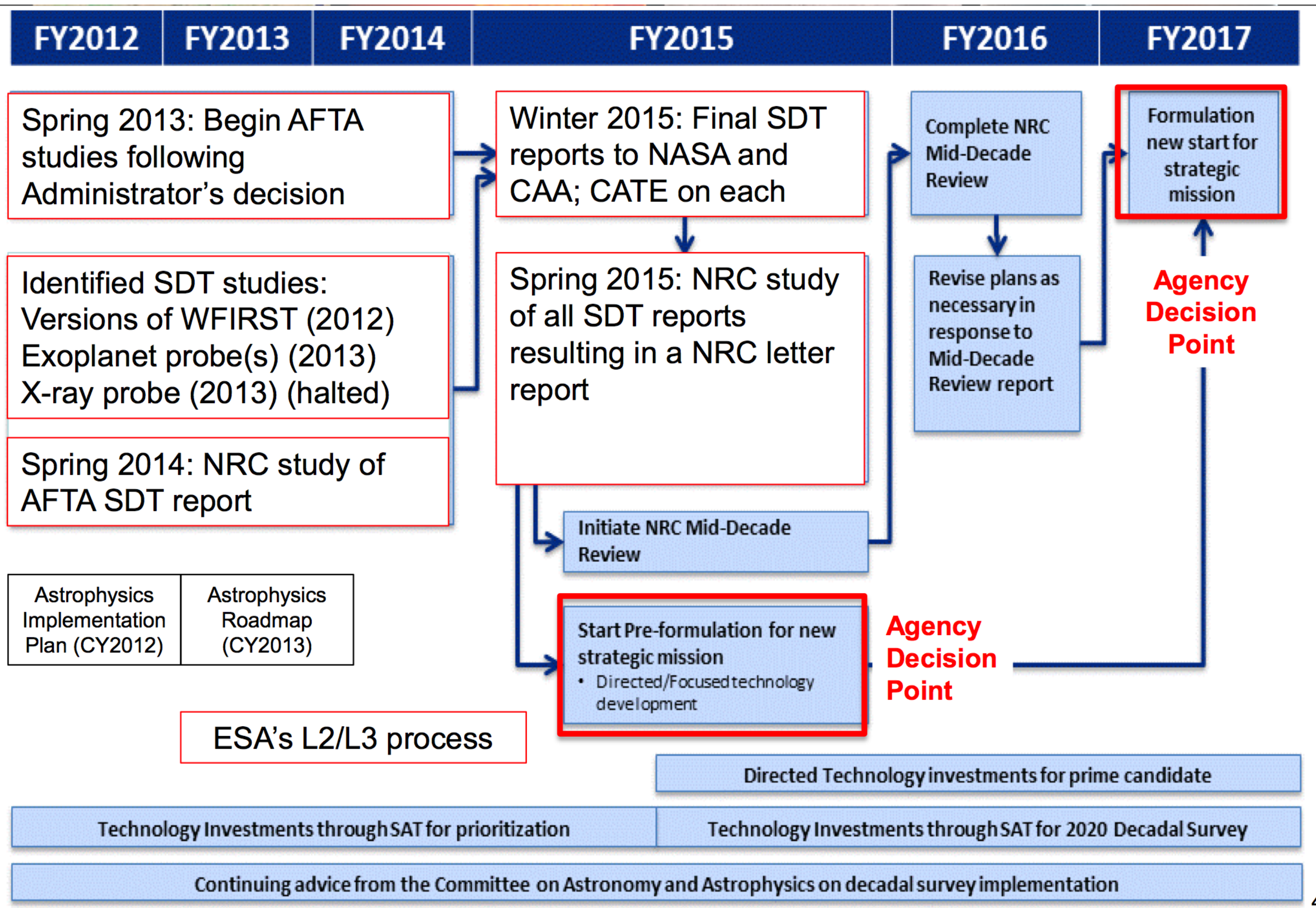
Recommendations from NRC Reviews

- 2000 Decadal (aka AANM, 2001)
  - Second priority behind GLAST (now Fermi) in the moderate category.
- Connecting Quarks with Cosmos (aka Q2C, 2003)
  - Proceed with an advanced technology program to develop instruments capable of detecting gravitational waves from the early universe
- Beyond Einstein Program Assessment (aka BEPAC, 2007)
  - The flagship mission of the program, after LPF launch
- 2010 Decadal (aka NWNH, 2010)
  - Third priority in the large category, conditioned on LPF success

The Astrophysics Division

- The budget anticipated in 2010 decadal didn't materialize.
- The Astrophysics Division and JWST
- Astrophysics Implementation Plan
  - Prepare for facility-class mission (WFIRST) or a probe
- WFIRST, the highest recommendation from 2010 decadal
  - Design concept evolved from decadal to probe to upscope
  - Gifted telescopes
  - Expanded exoplanet scope with addition of coronagraph
  - Congressional support for pre-project

Astrophysics Implementation Plan



Recent GW mission activities in the U.S.

- Concept study (2012)
  - No viable probe class mission exists
  - SGO Mid is the most reasonable compromise between science, cost and risk.
- Technology development roadmap (2013)
  - The eLISA and SGO Mid concepts require the same technology

STRATEGIC OPTIONS

Minor Partnership in L3

- NASA has expressed an interest.
- Advantages
  - Definite plan
  - Builds on strong European commitment in the past
  - Builds on long history of collaboration on LISA and LPF
  - May be compatible with NASA's willingness to invest
- Disadvantages
  - Very long range plan
  - Uncertain mission concept (as seen from NASA HQ)
  - Subject to slipping of L1, L2, L3, M3 and M4
  - Erosion of technical readiness
  - Uncertain U.S. role, weak hand in 2020 decadal

NASA-led, SGO Mid

- NASA lead has been the NRC recommendation.
- Advantages
  - Strong(er) hand in 2020 decadal
  - NASA has a history of successfully carrying out large and complex missions.
  - NASA has strong systems engineering.
- Disadvantages
  - There is no plan.
  - Requires strong performance in highly competitive 2020 decadal
  - Astrophysics may have few new missions in 2020's, after HST de-orbit, WFIRST launch in 2025, slipping and unpredictable budgets
  - Technology development would be non-standard
  - Unclear role for ESA and other potential partners

2020 DECADAL

2020 Decadal Process

- The 2020 process is undefined, but planning has started.
- What happened last time over a 2+ year period
  - Pre-decadal costing
  - Science white papers: 9 responses, 70 pages total
  - RFI 1: 20 page response to questionnaire, >300 received
  - RFI 2: 92 page response to questionnaire, 22 requested
  - Written questions: 18 page response
  - Public meetings: 2 public meetings, 5 town halls, 3 workshops
  - Community outreach blitz
  - Web sites at JPL, GSFC and Europe: 6 primary documents, 9 secondary documents, 693 pages total
  - Panel interview: 2 days, 122 slides
- Science white papers in 2018, recommendations in 2020

State of the chessboard

- Science events: B-mode reports, LIGO detections, PTA detections, time-domain astronomy
- Missions/projects: Kepler, TESS, JWST, LSST, WFIRST
- Competition
  - HST de-orbit
  - Exoplanet missions
  - Large UVOIR telescope (e.g., ATLAST)
  - CMB mission(s)
  - Renegade x-ray proposal
- The curse of Jon Morse: You will always end up in second place to a telescope.

Beyond the 2020 decadal

- "Golden moments" (Kennel and Dressler, Jan. 10 issue of *Science*)
  - A mission concept needs to do well in the decadal
  - The Agency needs adequate budget to carry out the recommendations.
  - The "stakeholders"
    - SMD and the Administrator
    - Office of Management and Budget (OMB)
    - Presidential Science Advisor and the Office of Science and Technology Policy (OSTP)
    - Congress: congressional staffers, powerful members of Congress
  - Unexpected external events (e.g. AFTA telescopes)

What will NASA do?

- [The really speculative part!]
- Carry out a study to determine the community consensus for a strategy
- Prepare for the decadal
- The Program Office is concerned about sustaining the external community.
- Sustain the internal core team
- Maintain technical readiness, retire technical risks
- NASA’s motivation? NRC recommendations, science

What does the GW community need to do?

- The US community needs to settle on a strategic plan.
- Whatever plan we choose
  - Prepare for the 2020 decadal with
    - A science case, preferably with exciting, new science
    - A well-understood mission concept, with a robust costing
    - A programmatic concept for technology development and international partnering
  - Ready before 2018! ~3 years.
- The international community needs to understand that there are complicated, internal US dynamics.

Space-Based Gravitational-Wave Astrophysics in the US

Neil J. Cornish

- US Science Developments since LISA IX
- LISA-Pol: eLISA with a US boost?
- The Gravitational Wave Decade
- Refreshing the Science case - fertile areas for future research

US Science Developments since LISA IX

1207.4848 "Prospects for observing ultra-compact binaries with space-based gravitational wave interferometers and optical telescopes", Littenberg, Larson, Nelemans, Cornish

1209.6286 "Astrophysical Model Selection in Gravitational Wave Astronomy", Adams, Cornish, Littenberg

1211.0548 "Supermassive Seeds for Supermassive Black Holes", Johnson, Whalen, Li, Holz

CQG 30, 165017 (2013) "Possible LISA follow-on mission scientific objectives", Bender, Begelman, Gair

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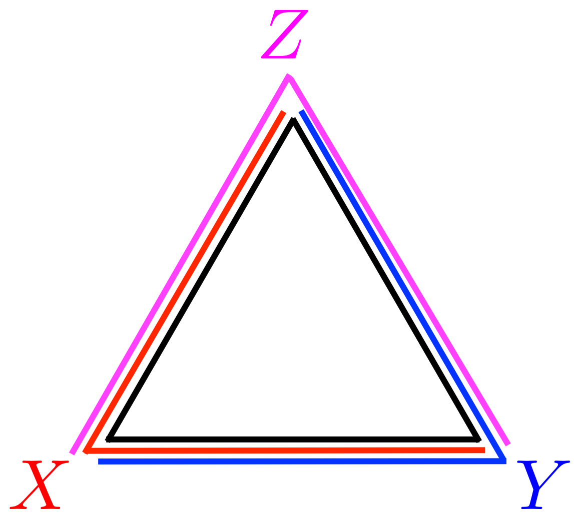
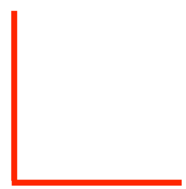
eLISA-Pol: Measurement benefits of 3-arms



Three interferometers!

$$S_{+} = \frac{\sqrt{3}}{2} X$$ $\Rightarrow$ 

$$S_{\times} = \frac{1}{2}(X + 2Y)$$ $\Rightarrow$ 

Instantaneous measurement of both polarization states and increased signal-to-noise

$$S_{\odot} = \frac{1}{3}(X + Y + Z)$$ $\Rightarrow$ 

Null channel to monitor average low frequency instrument noise

eLISA-Pol: Science Gain from 3-arms

- More Sources

- x 3 Extreme Mass Ratio Inspirals
- x 2 Galactic Binaries
- x 10 Low Mass Seed Black Holes

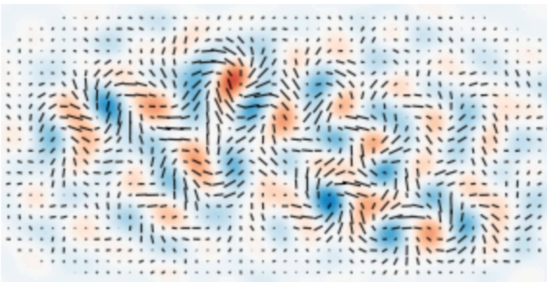
- Better Measurements

- x 1.5 Well Localized Galactic Binaries
- x 7 Well Localized Massive Black Hole Mergers
- x 5 Black Hole Systems with Precise Spin Determination

- Wider Discovery Space

- Enable the unambiguous detection of a stochastic background
- Confident detection and characterization of exotic signals

2010's: The Decade of Gravitational Waves

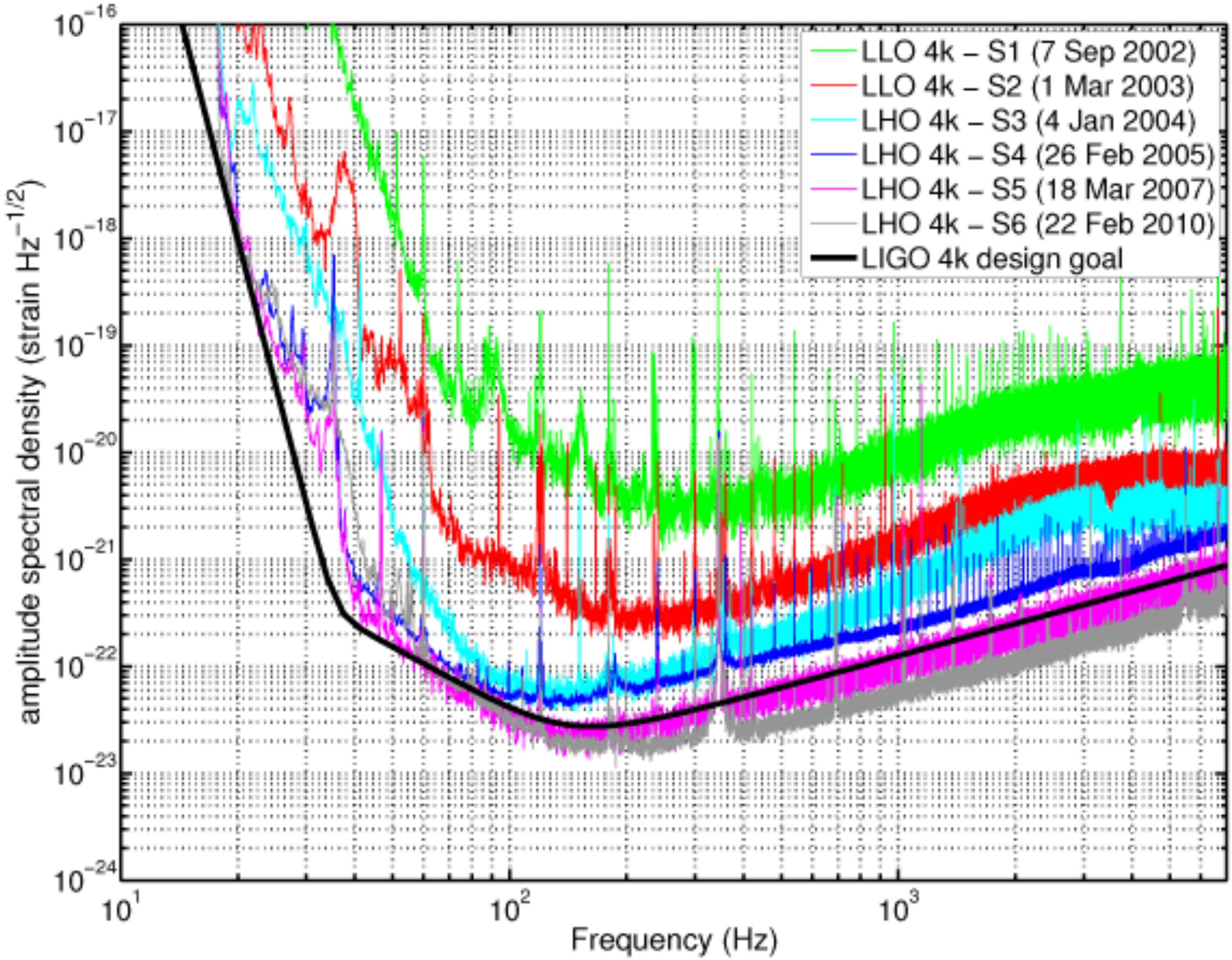


- BICEP2 detection in 2014

- LIGO/Virgo detection in ~ 2016

- IPTA detection in ~ 2018

LIGO sensitivity over time



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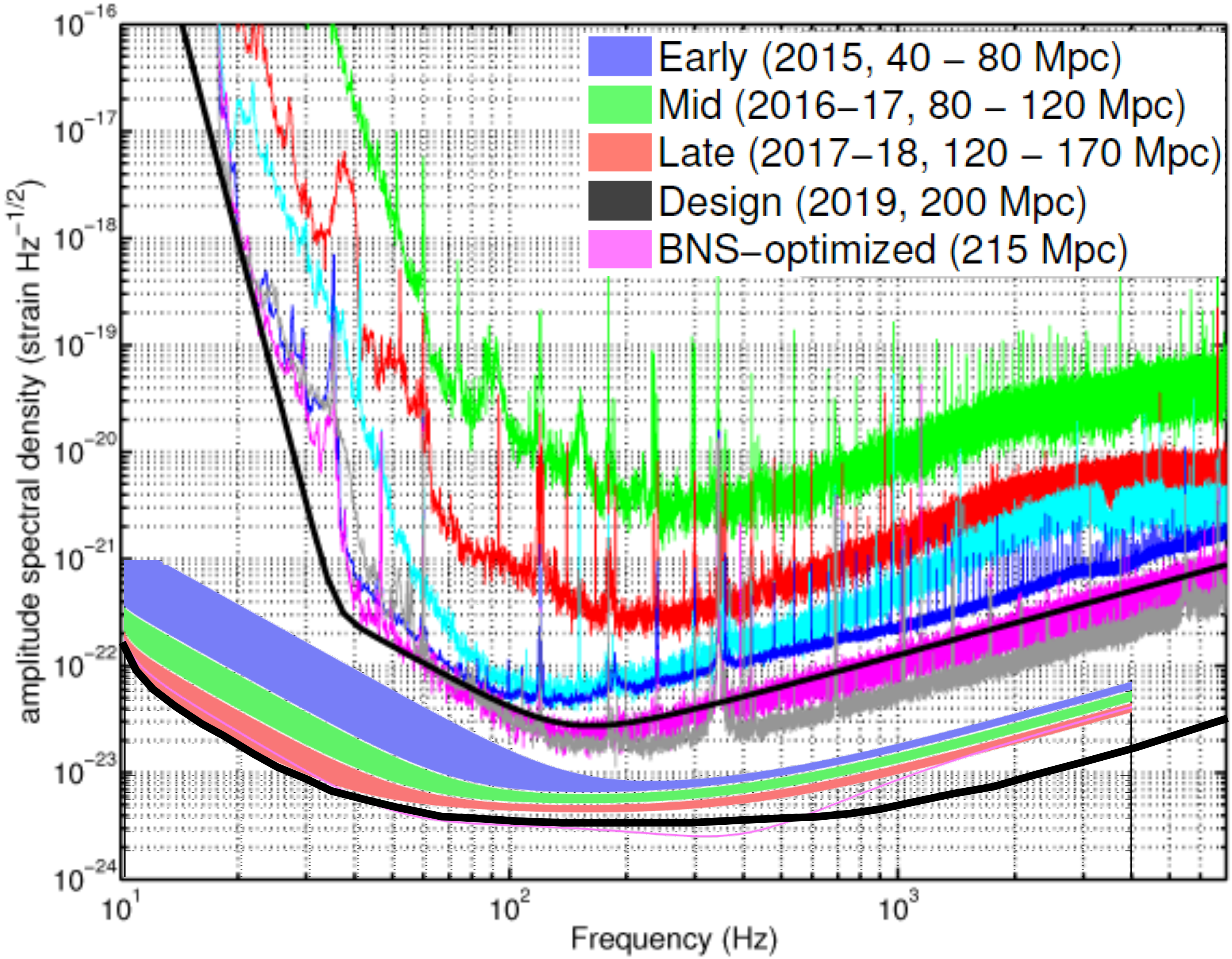
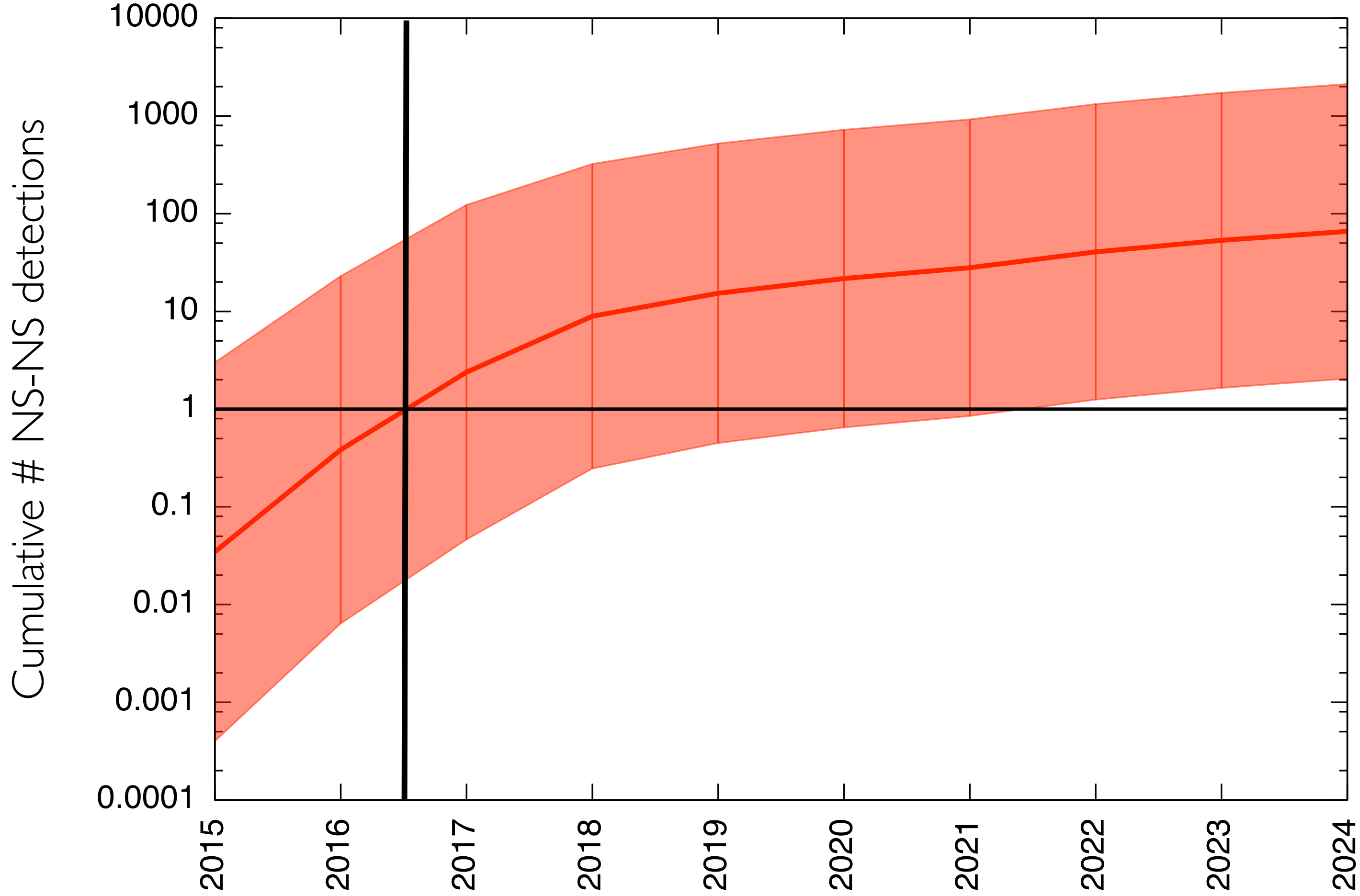
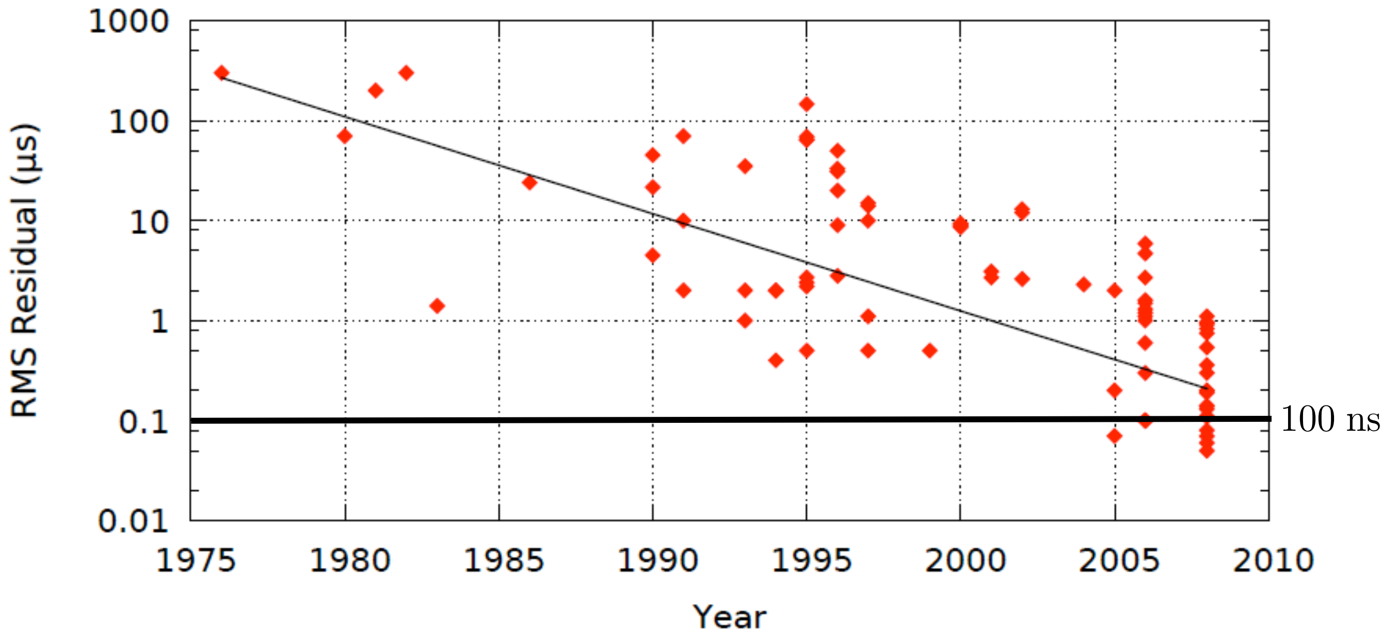


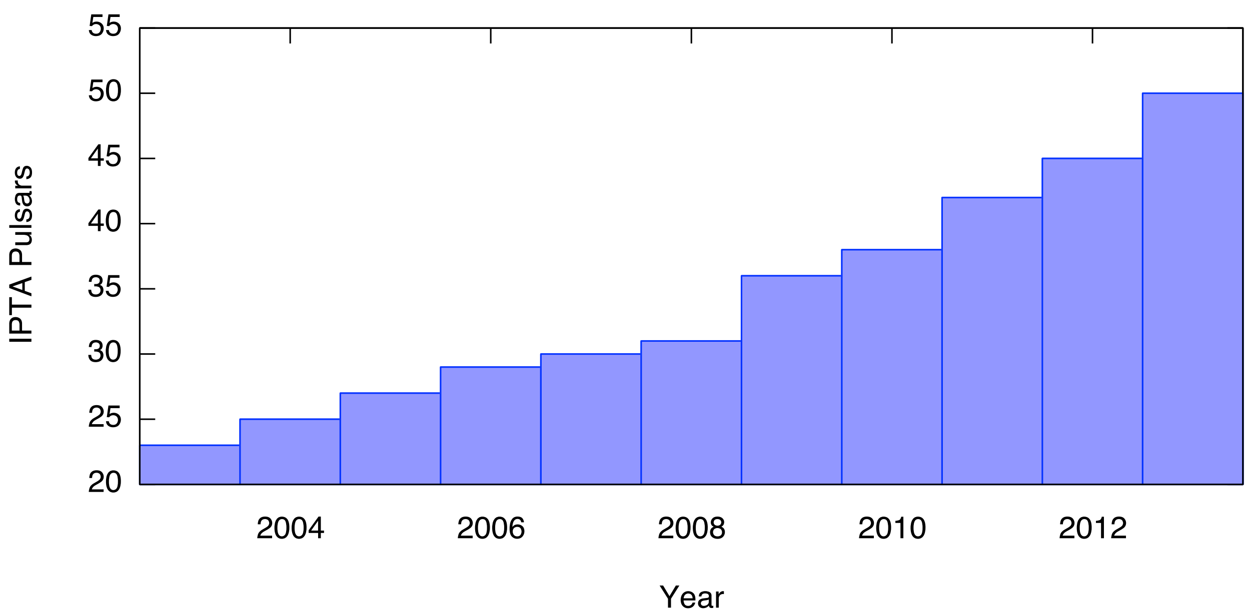
LIGO/Virgo Prediction



[LIGO & Virgo Collaborations, arXiv:1304.0670 (2013)]

Pulsar Timing in hot pursuit





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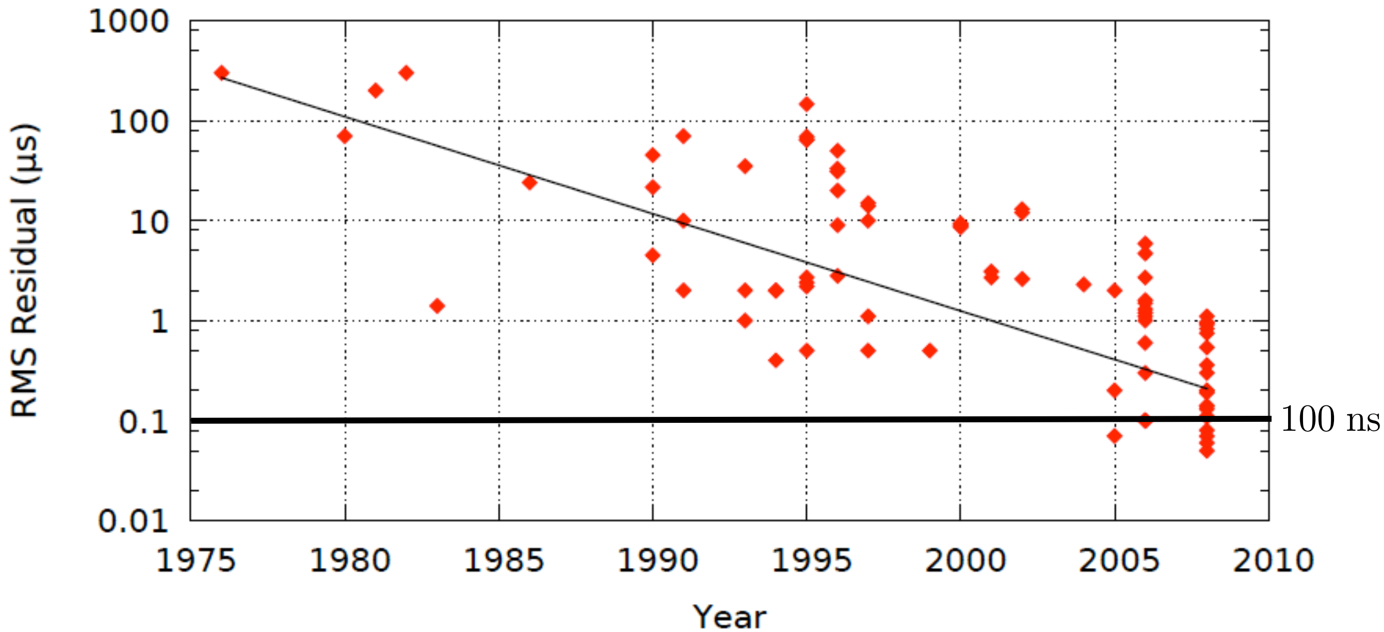
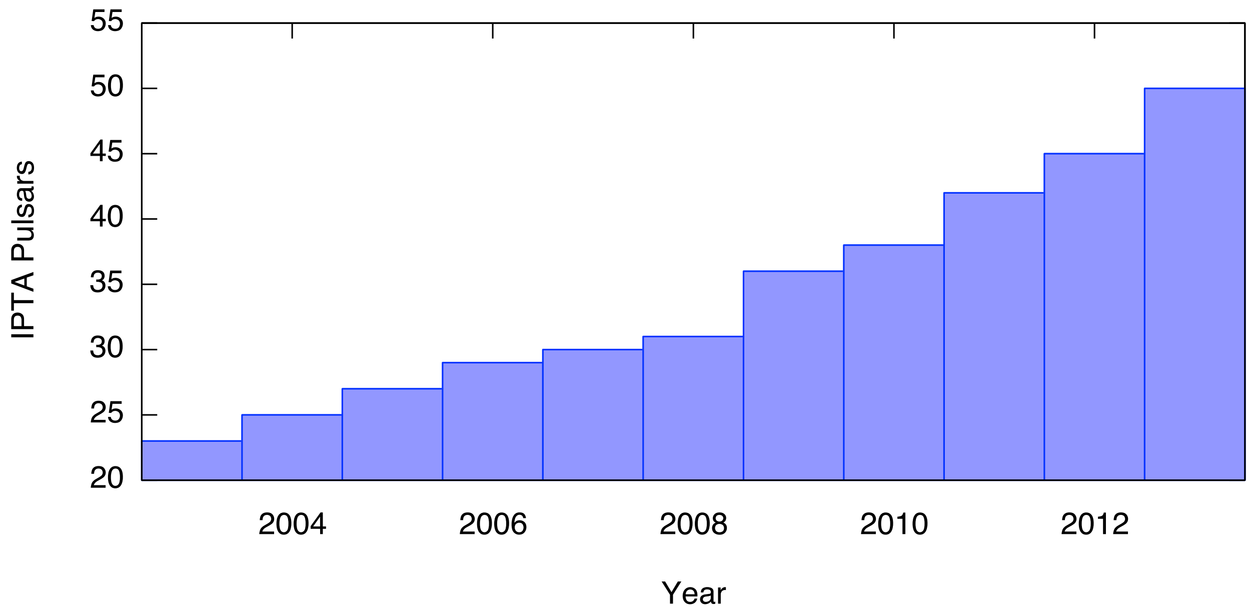
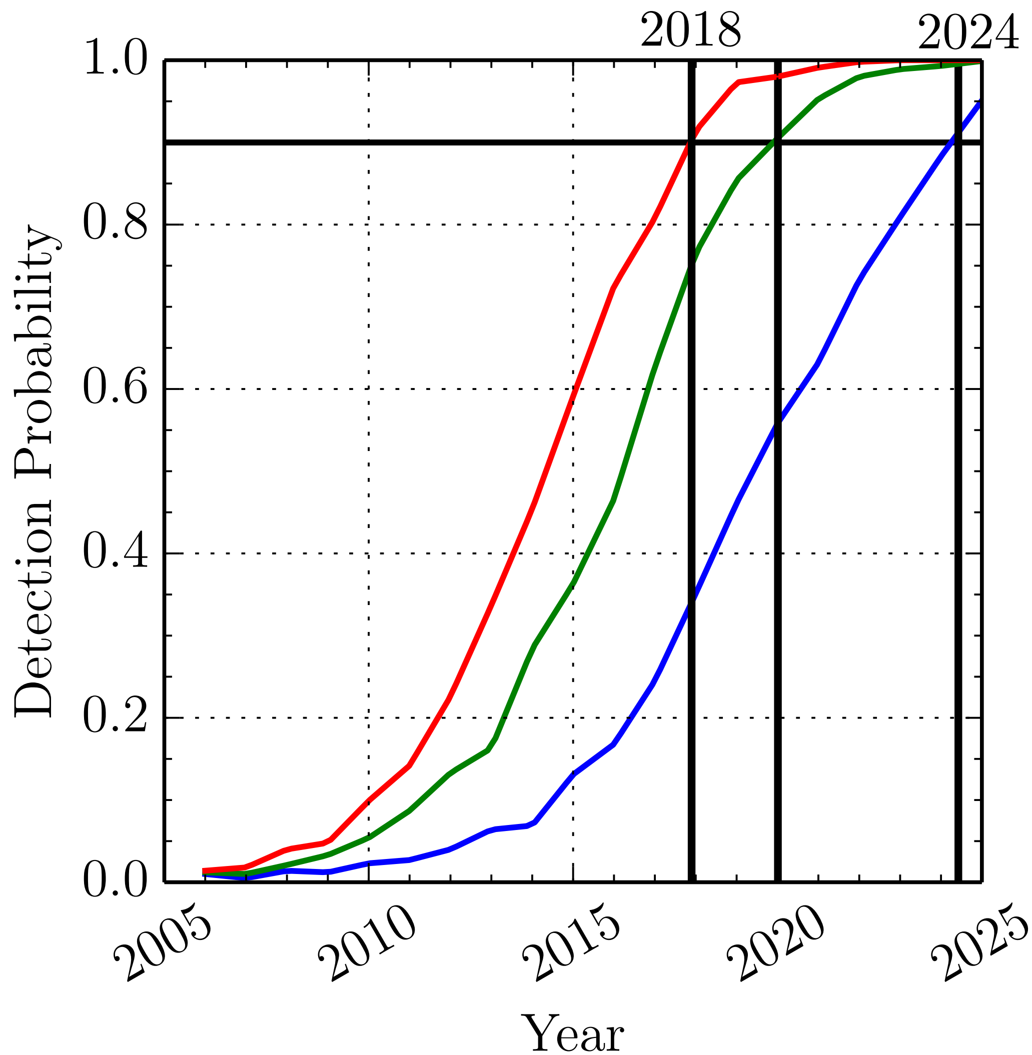


Likely detection with ~40 pulsars at ~100 ns timing accuracy



Pulsar Timing: NANOGrav Prediction



[X. Siemens, J. Ellis, F. Jenet, J. Romano, Class. Quant. Grav. 30, 224015 (2013)]

Refreshing and Expanding the Science Case

Fertile areas for study

(aka, pages from my last four grant proposals that NASA declined to fund)

BH Parameter Estimation

Fully consistent BH IMR waveforms, precession + higher harmonics now possible using the minimal rotation frame. Fast frequency domain implementation via the new uniform SPA technique (Klein, Cornish & Yunes).

Unexpected Sources

Develop data analysis for un-modeled signals (e.g. bursts).
2 arm versus 3 arm performance

Intermediate Mass Black Holes

Can these play a larger role in the science case?
Constraints on population synthesis models? EM counterparts?

Fertile areas for study

EMRI waveforms with resonances

Impact on detection algorithms and parameter estimation

Intermediate Mass Ratio Binaries

Hybrid waveforms (PN/Self Force)
Use in GR tests

Rare (yet loud) Galactic Binaries

Stellar BH-BH, BH-NS and NS-WD binaries
Overlap with LIGO/Virgo physics
Detect BH-BH binaries anywhere in galaxy for $f > 0.5$ mHz
Measure chirp mass of BH-BH binaries for $f > 1$ mHz