Status of gravitational wave observatories

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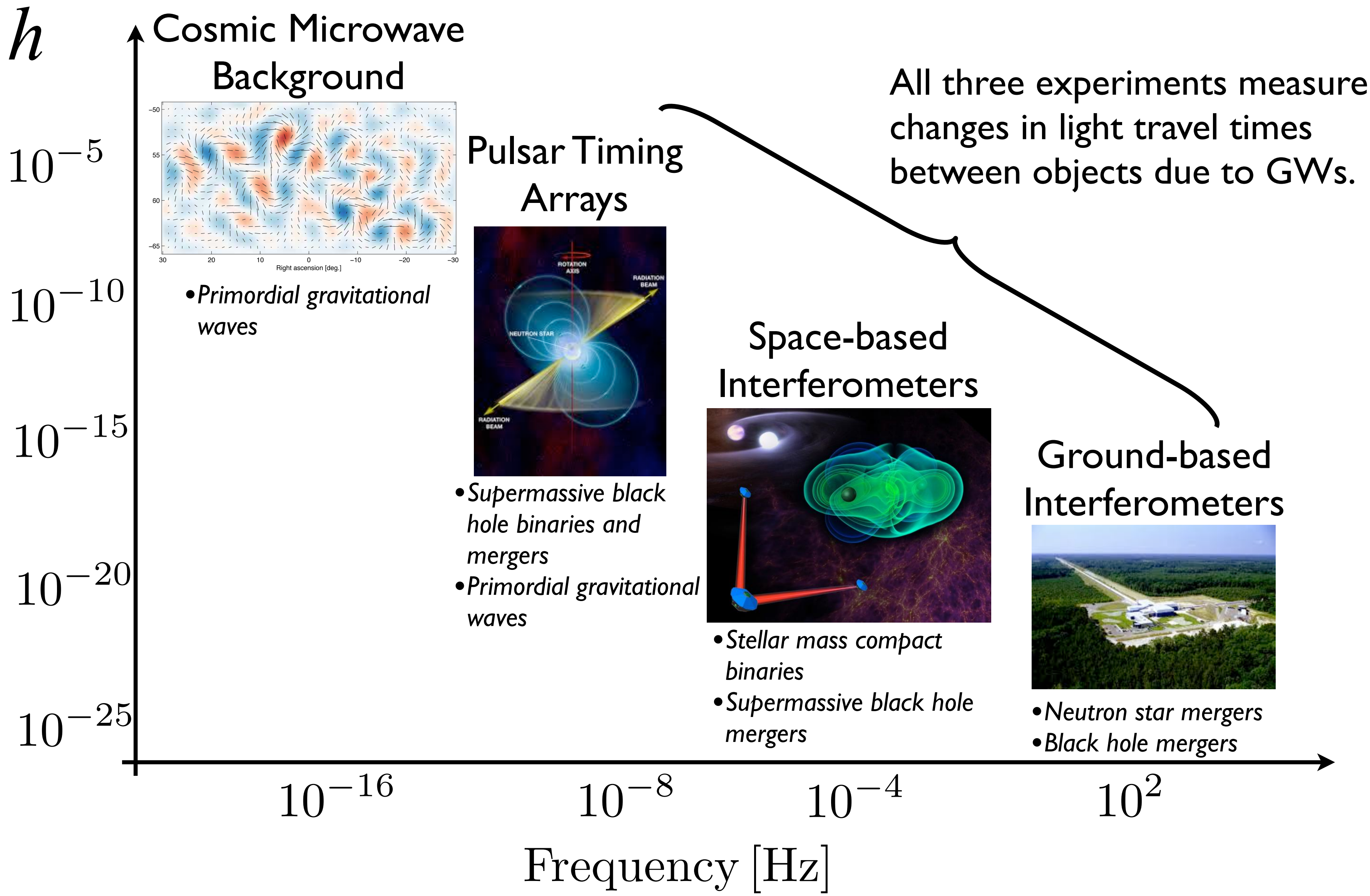
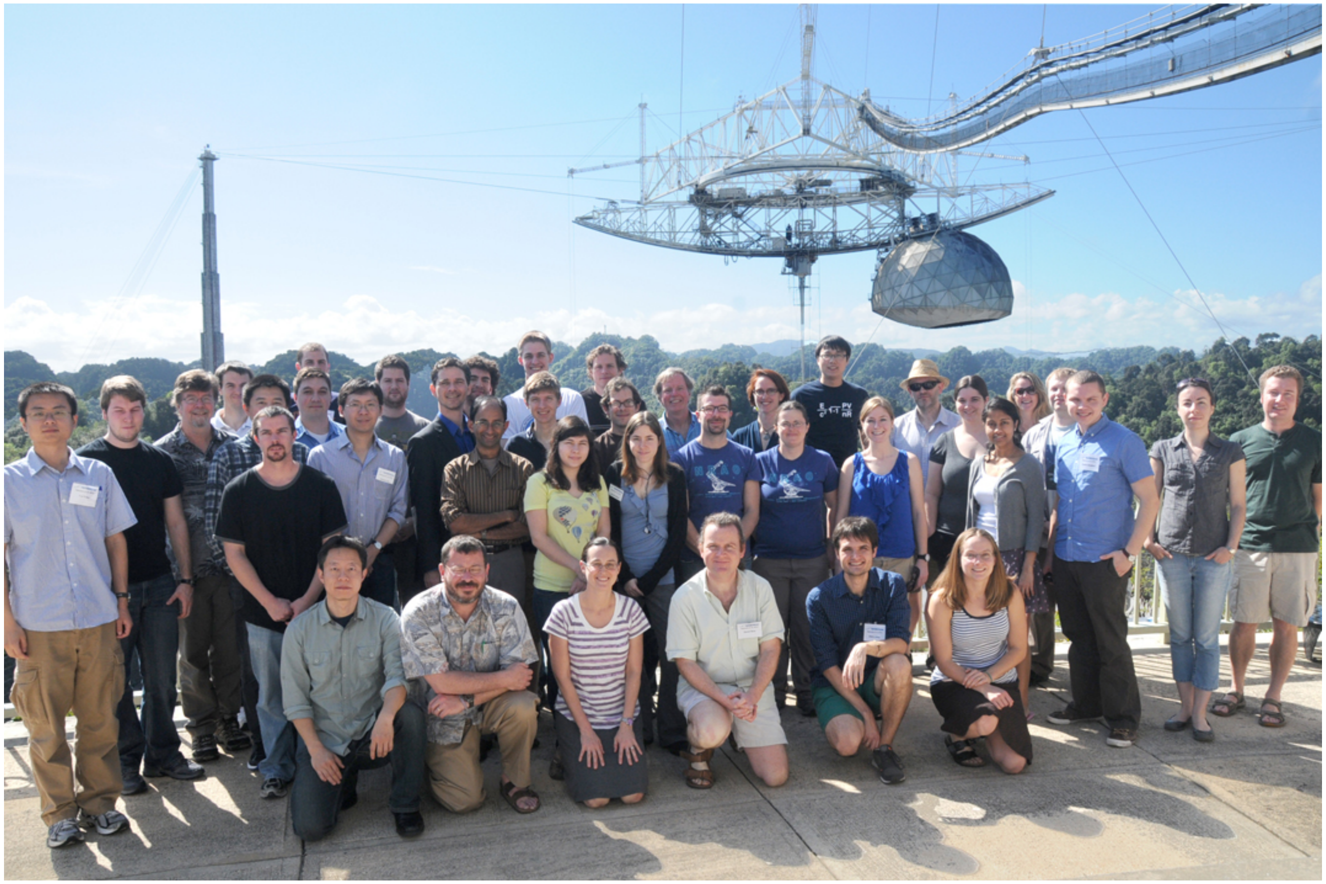
Gravitational wave experiments



Gravitational wave astronomy is happening now!

I. Pulsar timing arrays

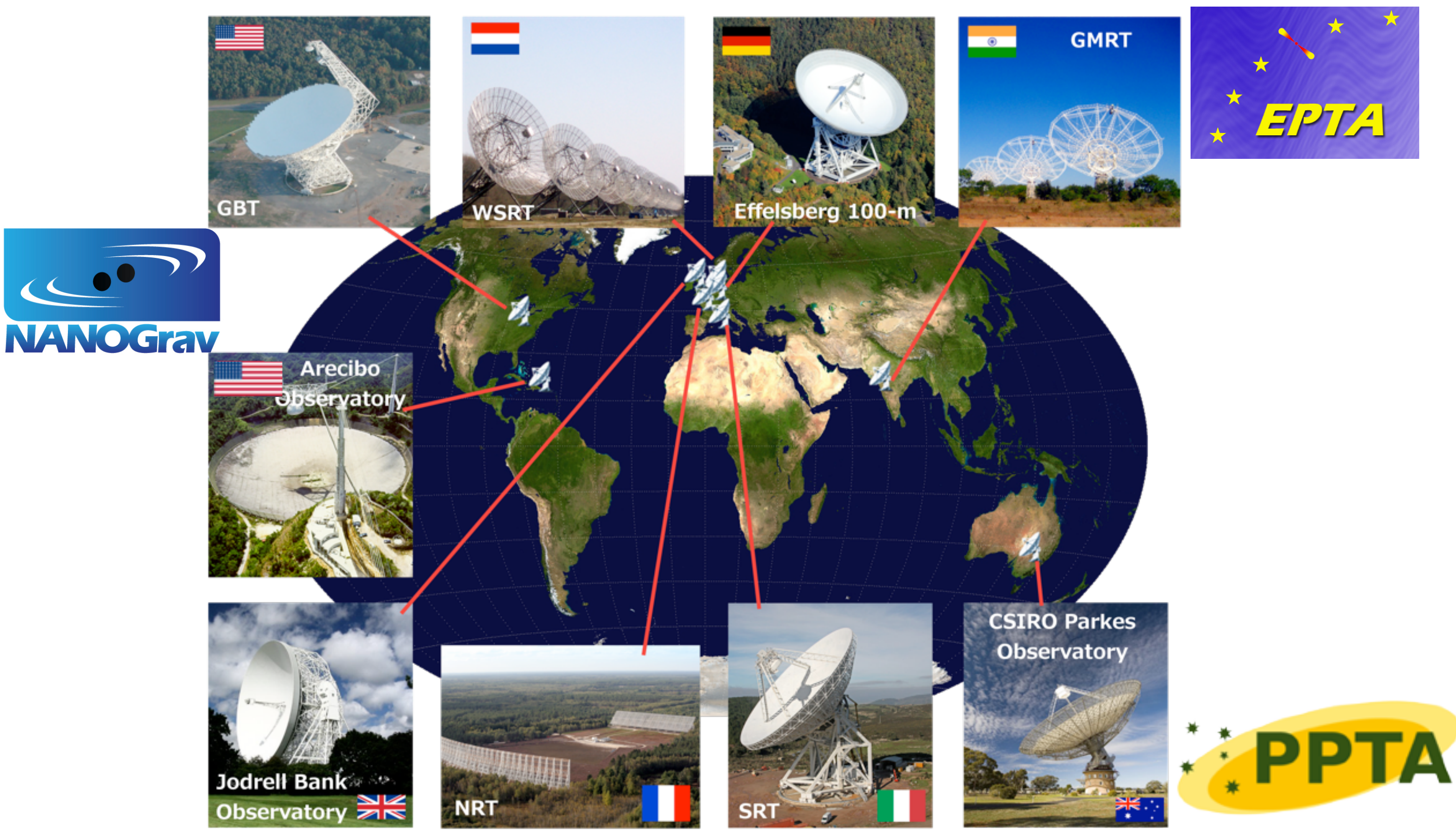
The North American Nanohertz Observatory for Gravitational Waves (NANOGrav): about 70 students and scientists in the US and Canada. Part of a world-wide effort including European and Australian partners.



NANOGrav currently funded by a Physics Frontiers Center with support from the AST MSIP program and the Office of Multidisciplinary Activities at NSF.

The International Pulsar Timing Array (IPTA)

Relationship between PTAs is one of cooperative competition. Data are shared six months after they are taken and analyzed through organized IPTA-wide projects.



The Arecibo Observatory and the Green Bank Telescope

NANOGrav measurements are made with the two most sensitive radio telescopes in the world

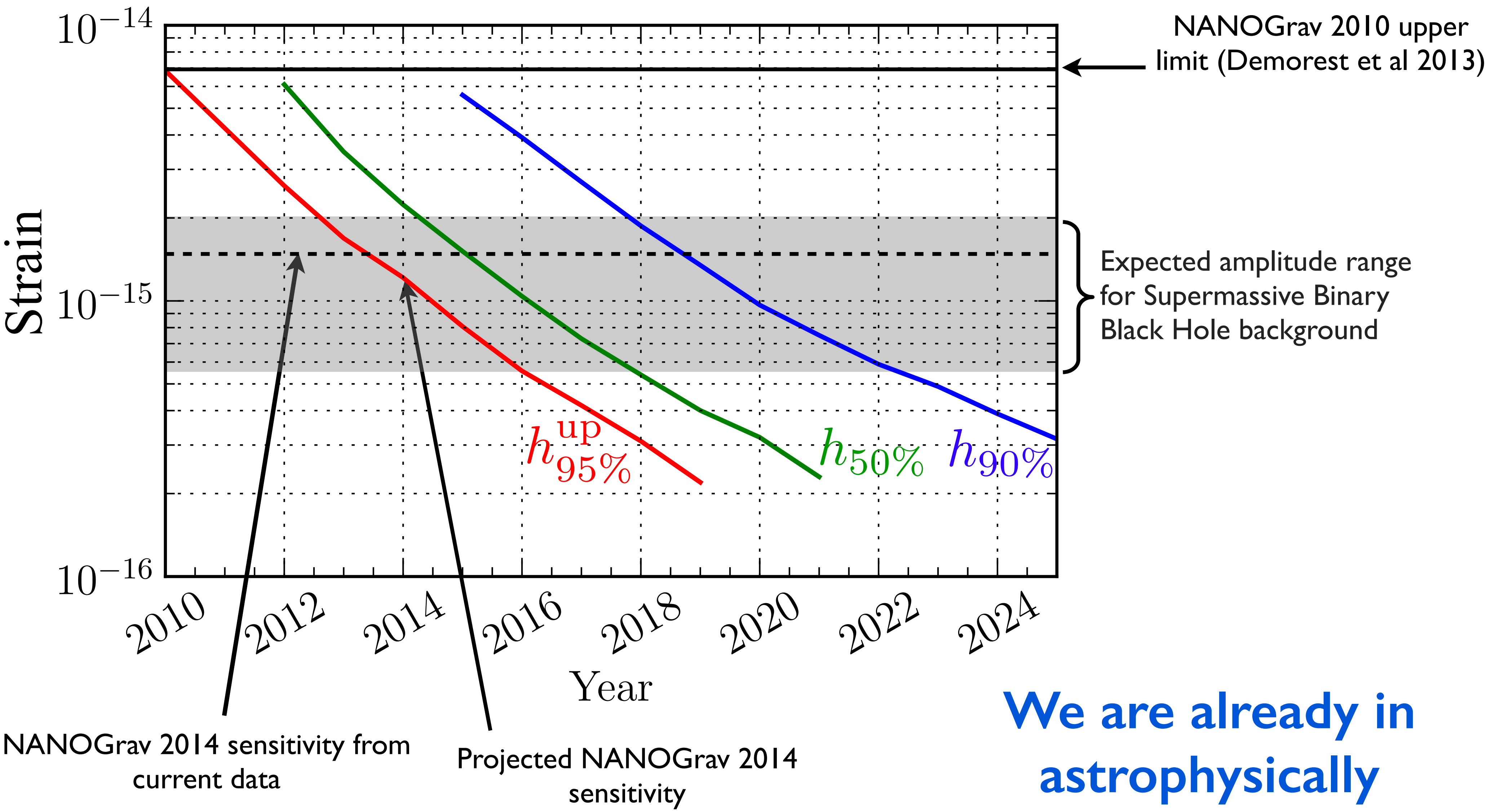
Arecibo Observatory (AO), PR
World's largest
radio telescope

Green Bank Telescope (GBT), WV
World's largest steerable
radio telescope

Dear Colleague letter 2015

NSF AST Portfolio Review 2013

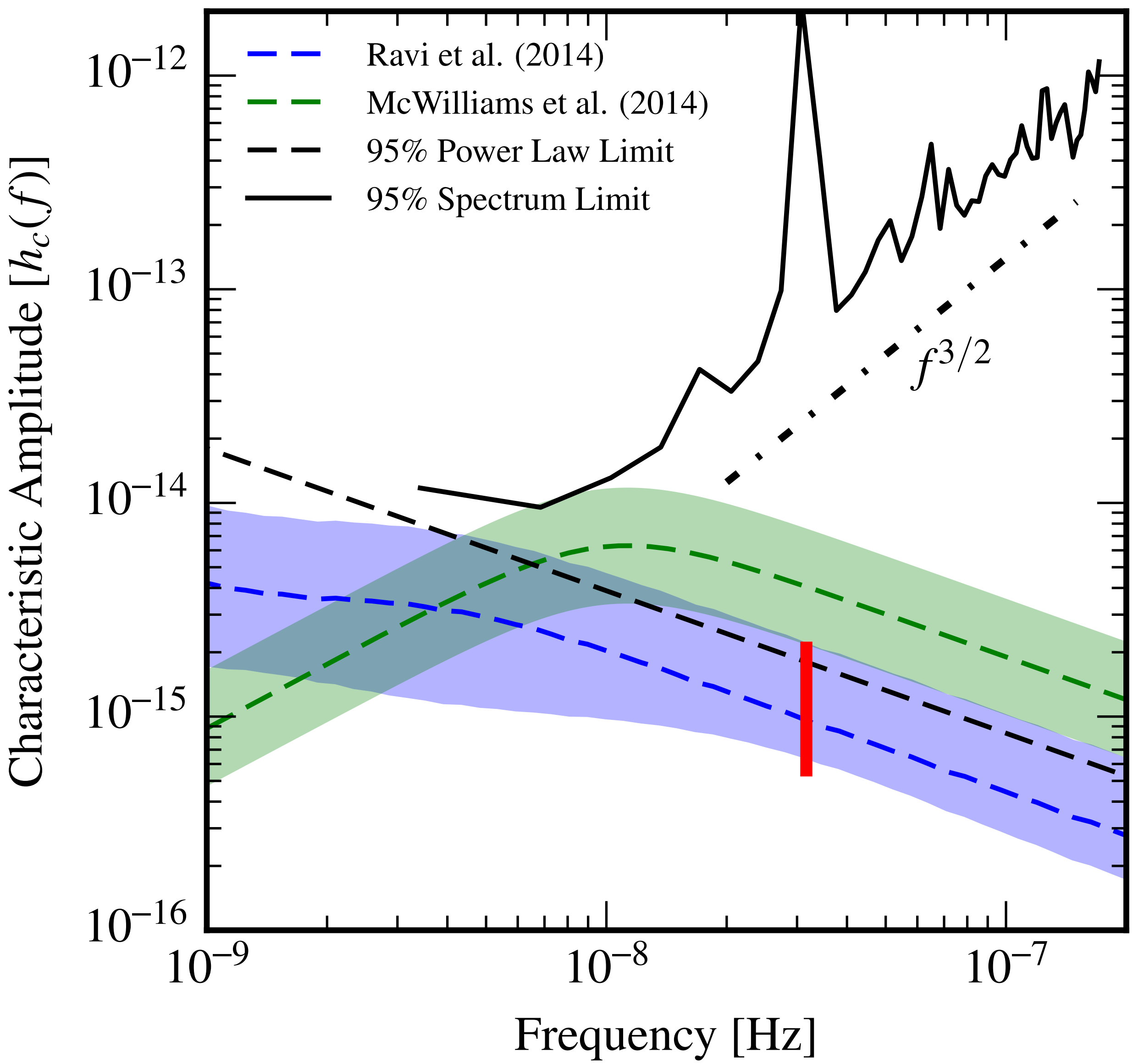
NANOGrav sensitivity projections



We are already in astrophysically interesting territory!

Latest stochastic background results

Arzoumanian et al. 2015 (arxiv, submitted to ApJ)

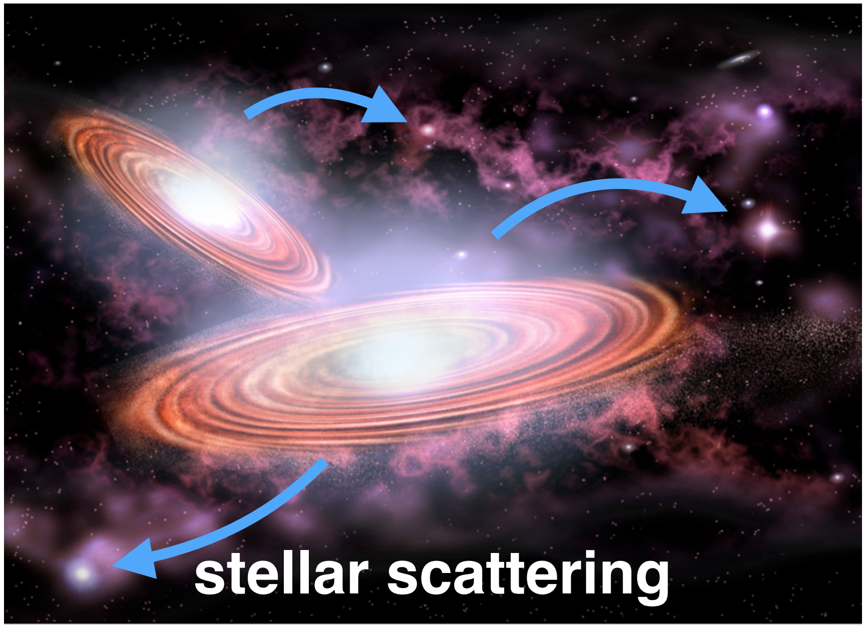


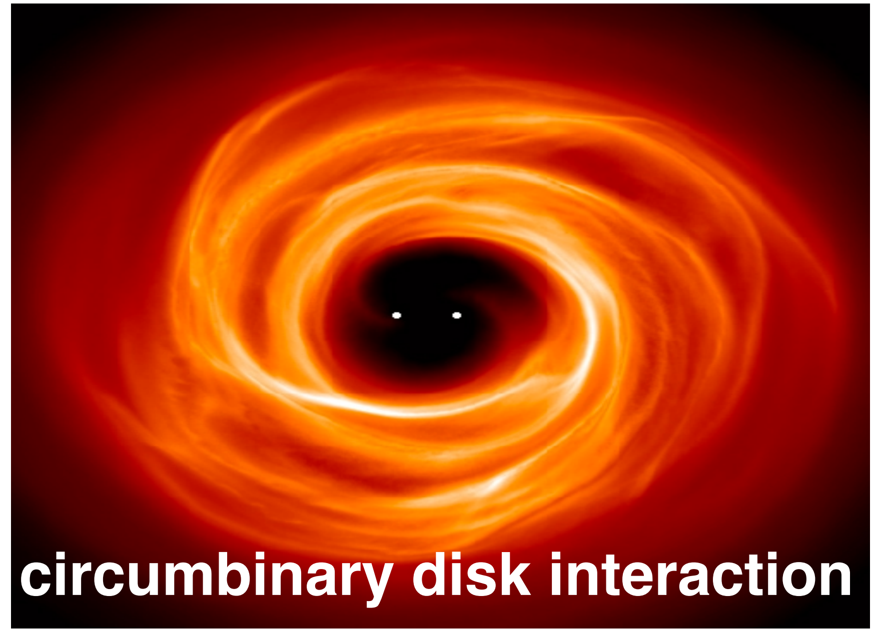
We are already in astrophysically interesting territory!

NANOGrav postdocs and students involved:

Sarah Burke-Spolaor
Justin Ellis
Chiara Mingarelli
Laura Sampson
Steve Taylor
Rutger van Haasteren
Joe Simon

SMBH Environmental Effects

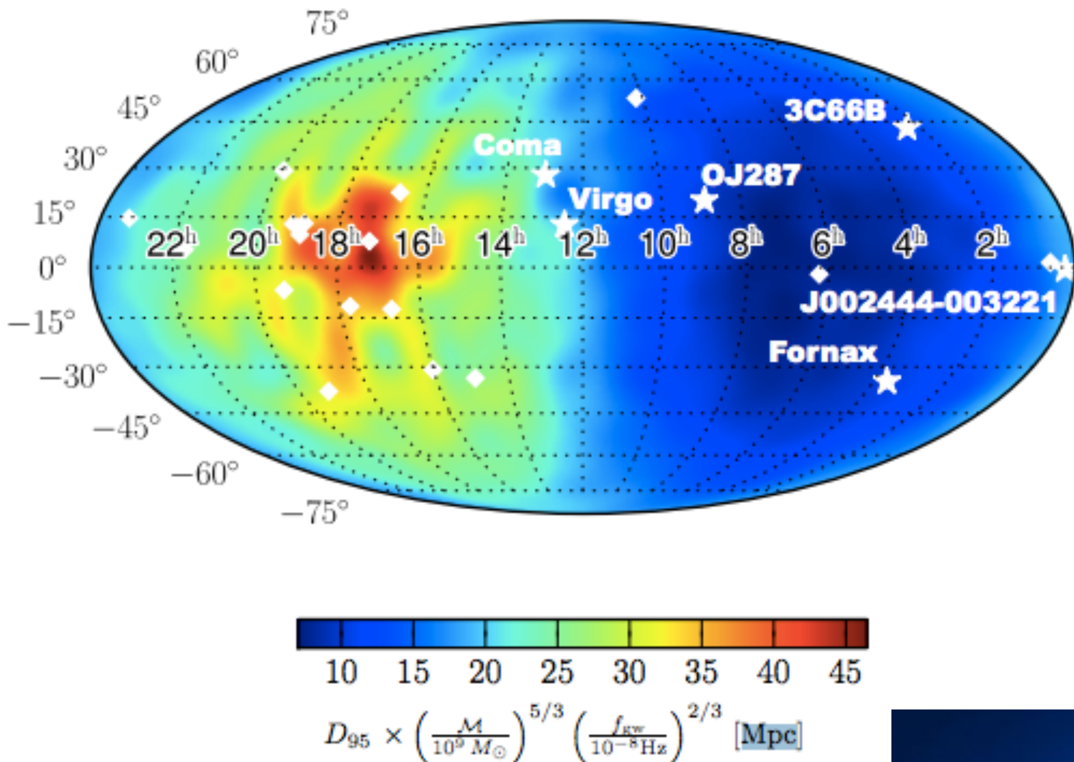




Courtesy: Steve Taylor

Continuous waves from individual SMBBH systems

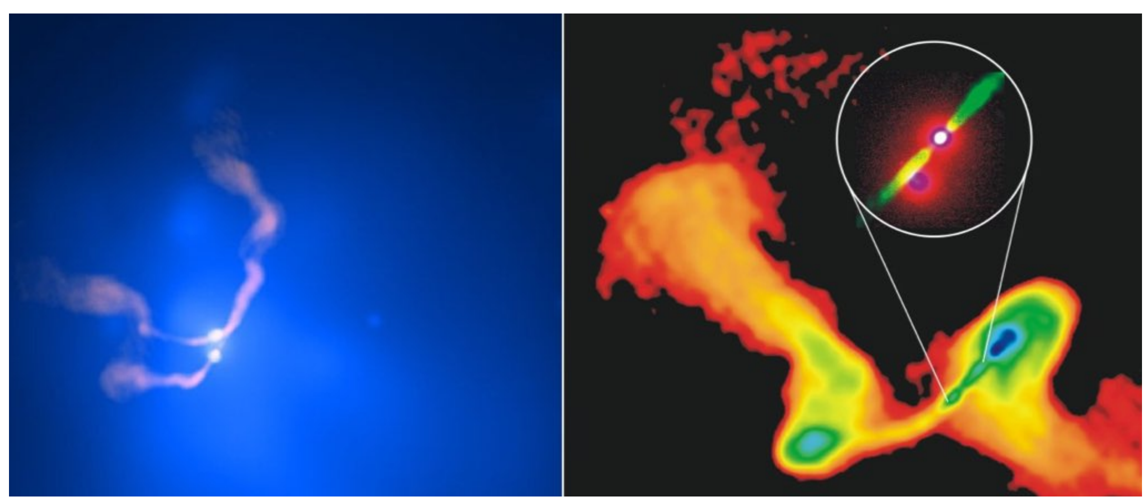
Arzoumanian et al. 2014 (ApJ)



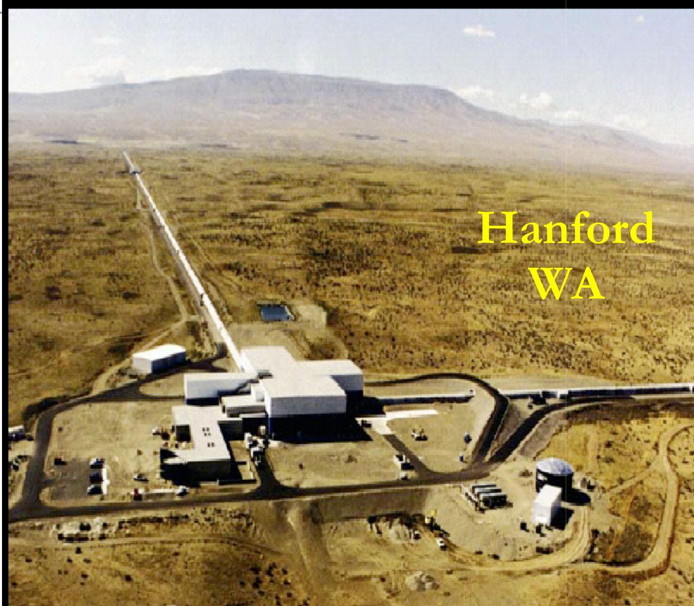
NANOGrav postdocs and students involved:

Justin Ellis

Exciting multi-messenger astronomy potential

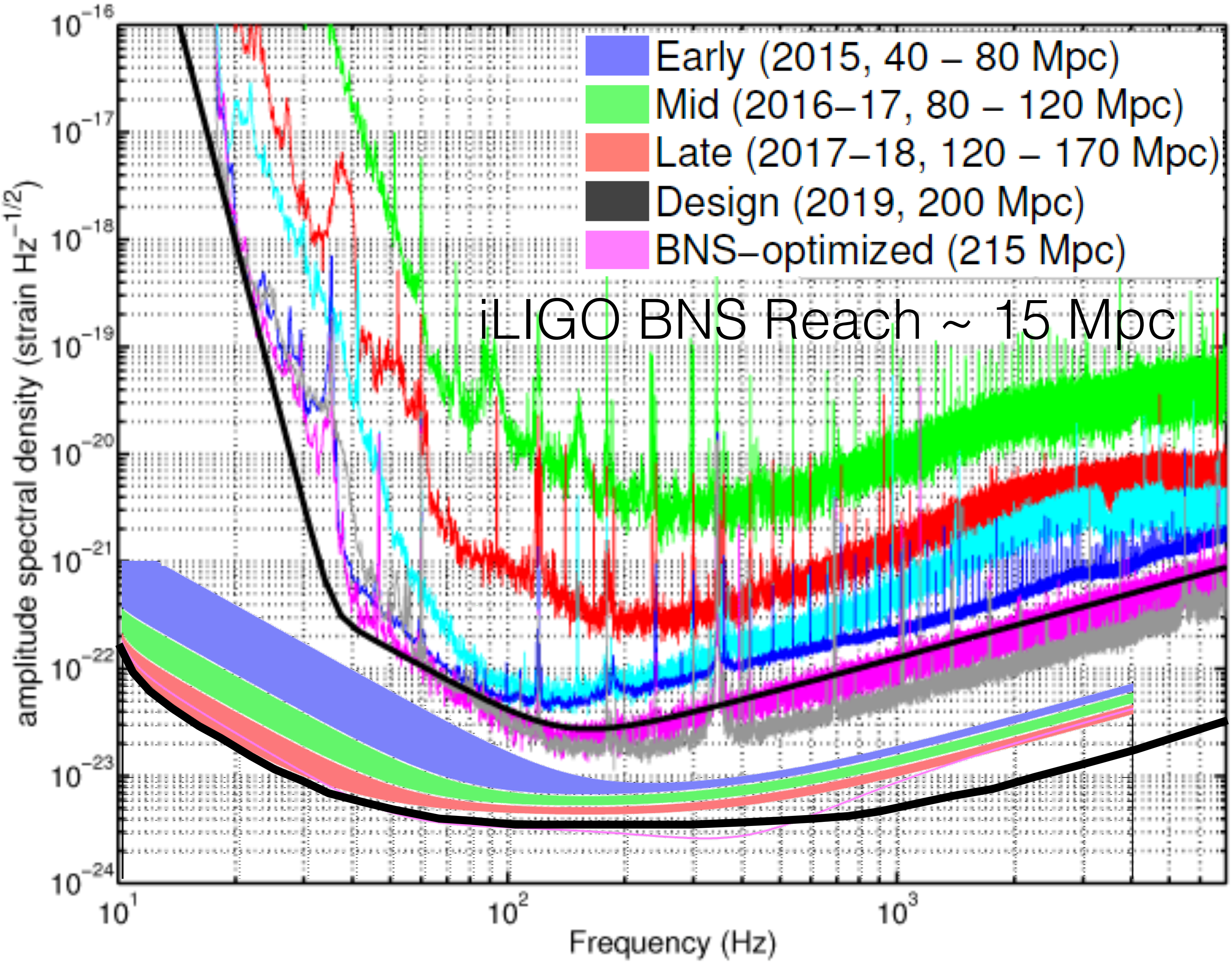


II. Ground base interferometers

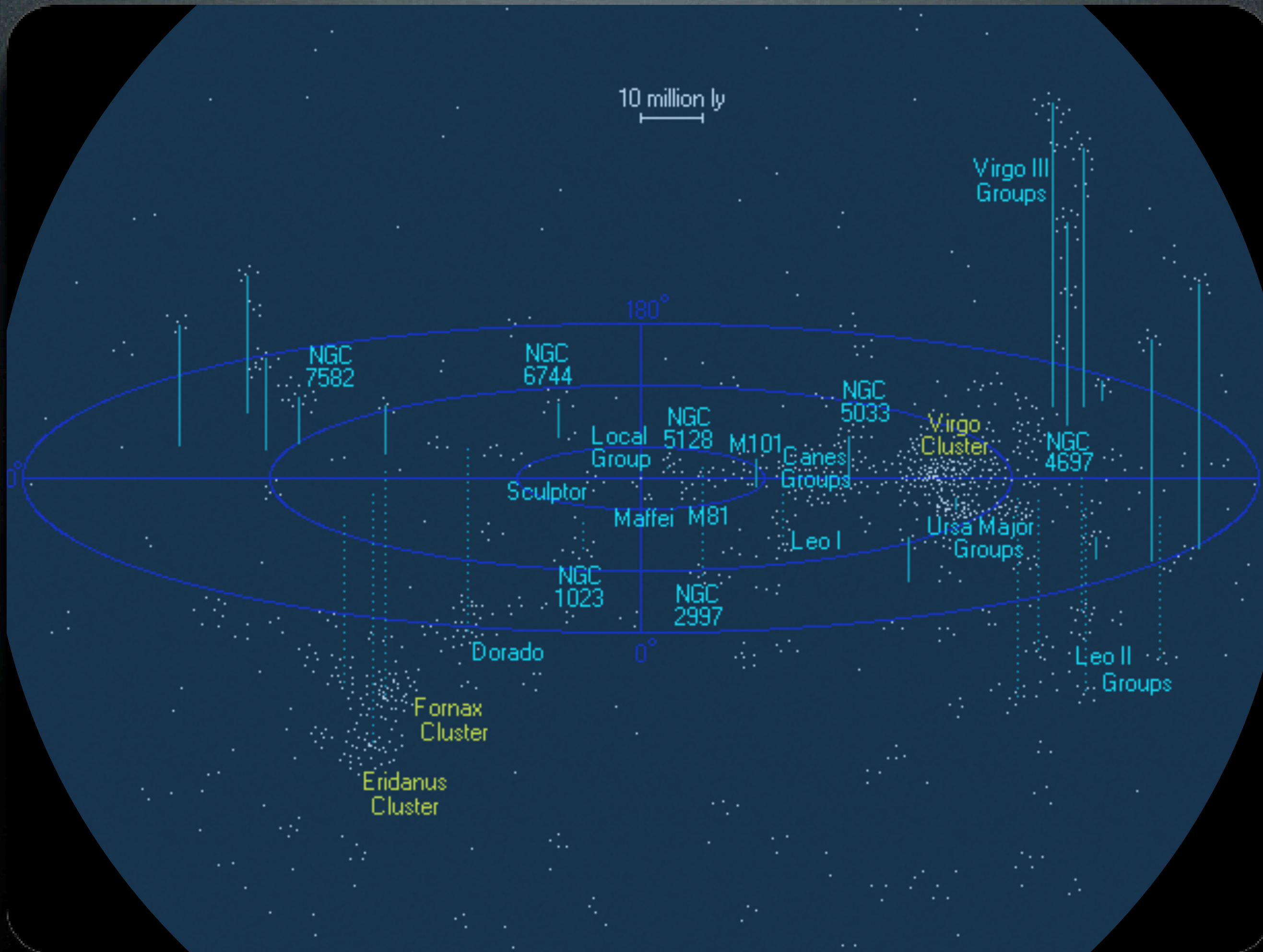


Global network of interferometers

LIGO sensitivity over time



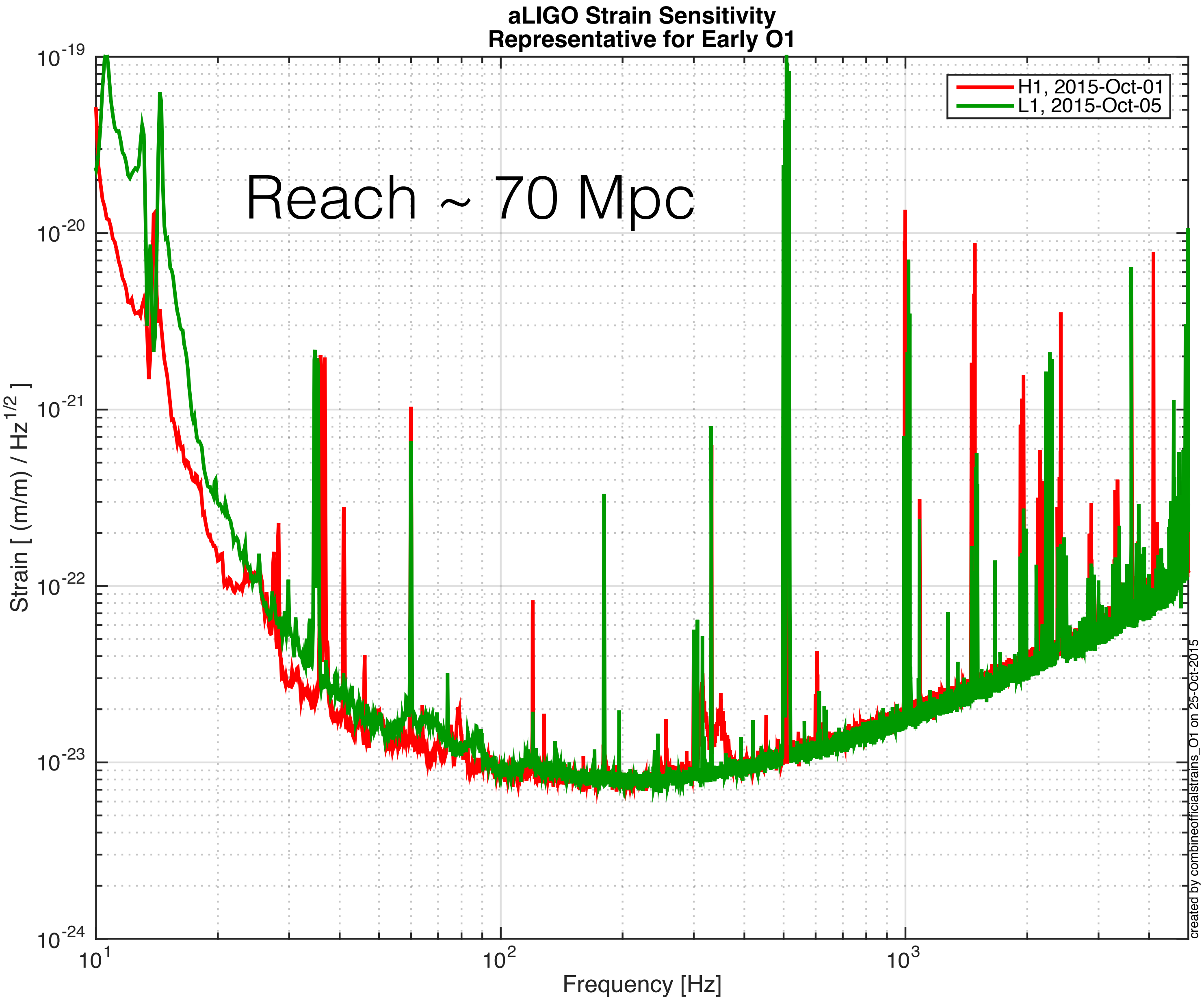
Initial LIGO (S5)



Binary Neutron Star Range

Credit: Jolien Creighton

Current state



Timeline

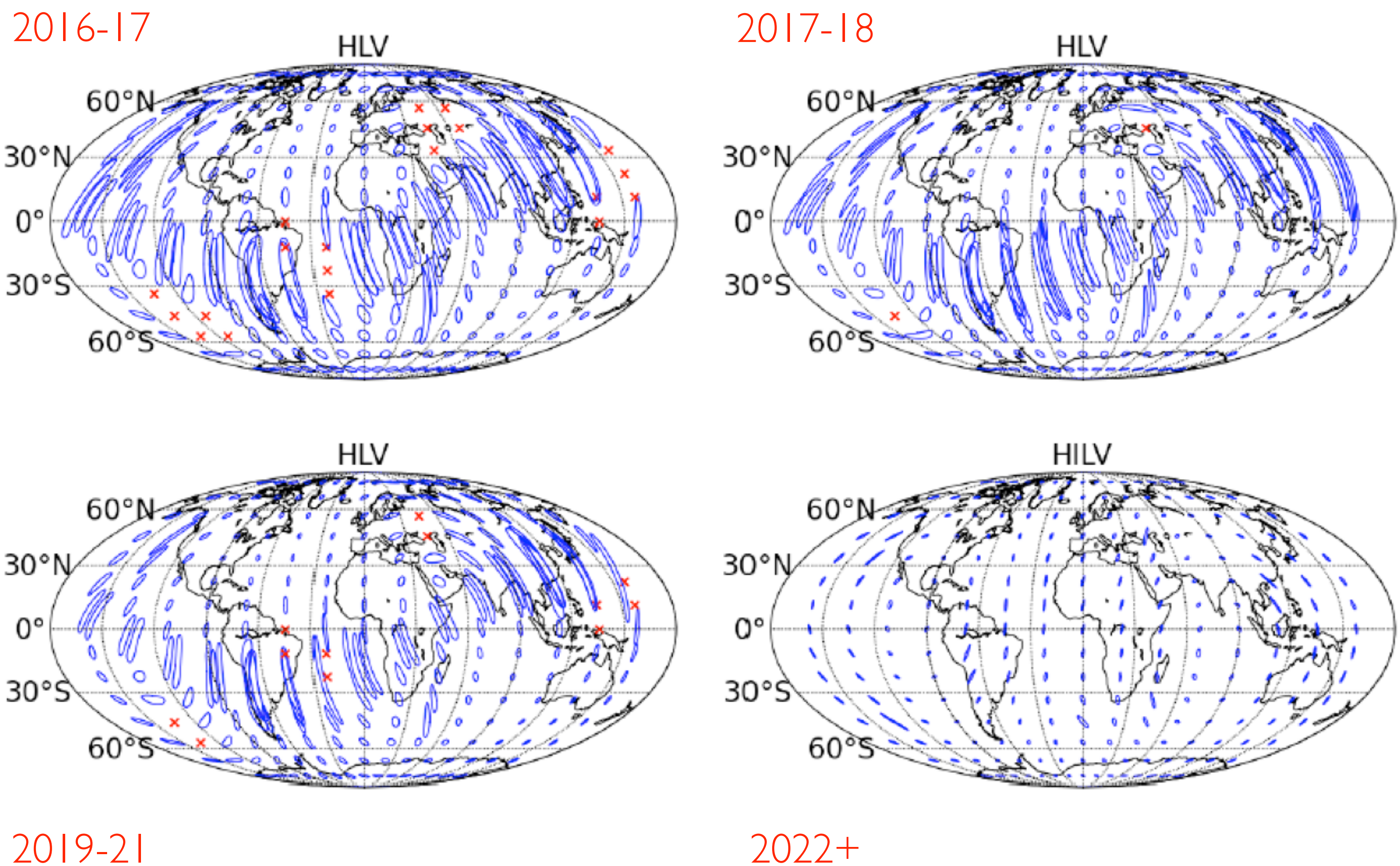
arxiv:1304.0670

Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

IFO	Source[a]	$\dot{N}_{\rm low}$ yr^{-1}	$\dot{N}_{\rm re}$ yr^{-1}	$\dot{N}_{\rm high}$ yr^{-1}
	NS–NS	2×10^{-4}	0.02	0.2
	NS–BH	7×10^{-5}	0.004	0.1
Initial	BH–BH	2×10^{-4}	0.007	0.5
	NS–NS	0.4	40	400
	NS–BH	0.2	10	300
Advanced	BH–BH	0.4	20	1000

arXiv:1003.2480

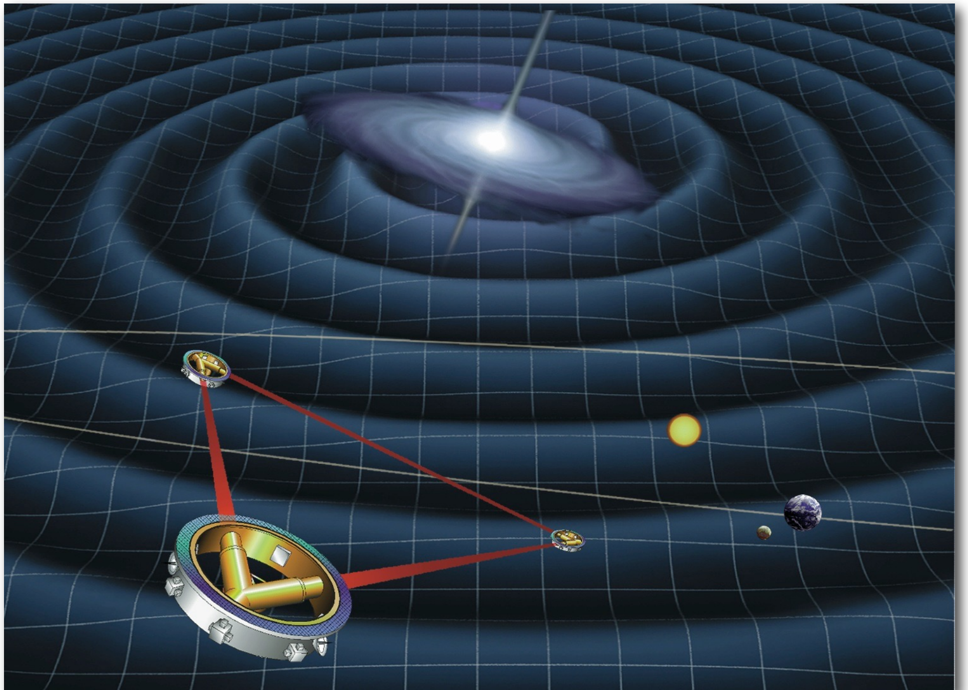
LIGO/Virgo Sky Localization - NS-NS mergers

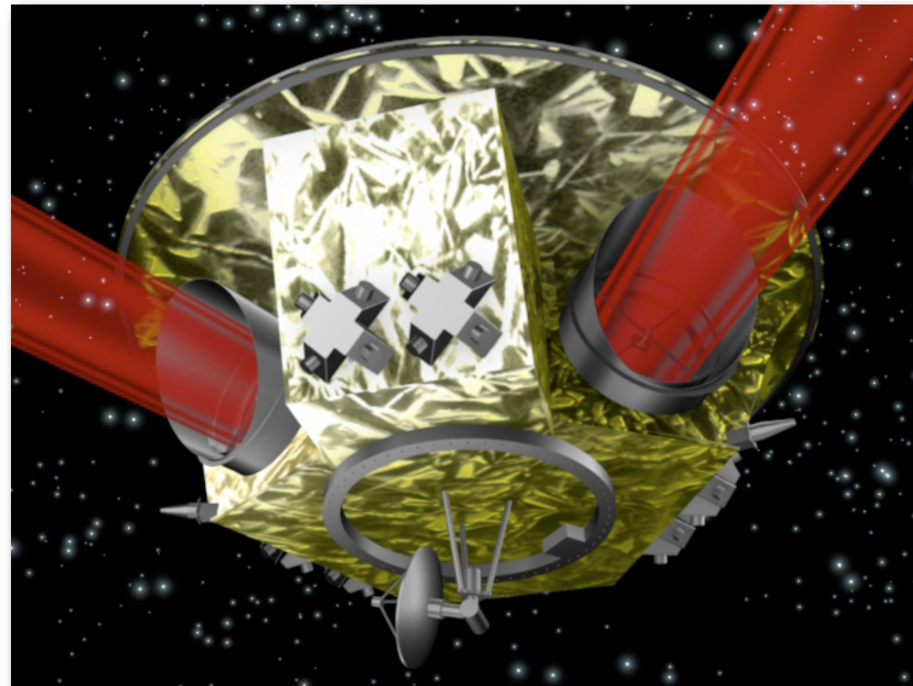


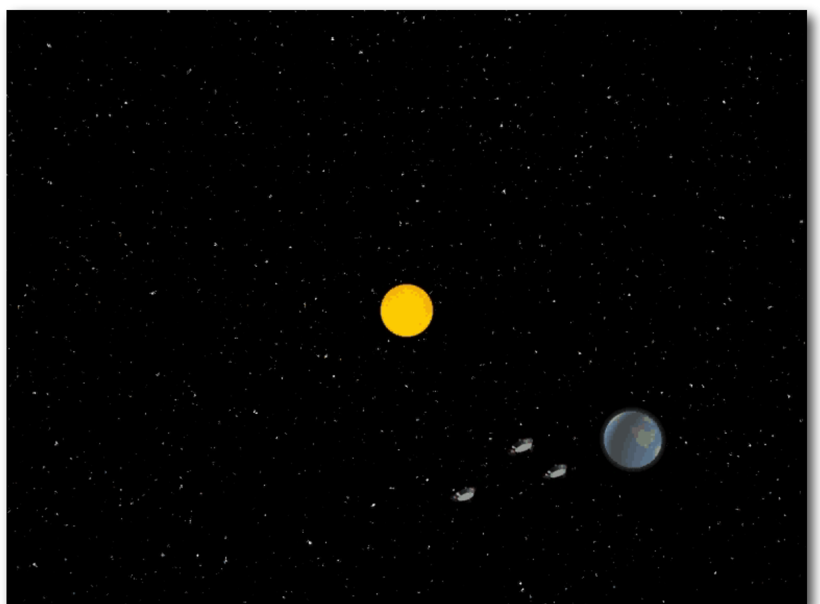
[LIGO & Virgo Collaborations, arXiv:1304.0670 (2013)]

MOUs agreed upon with many EM (and neutrino!) observers

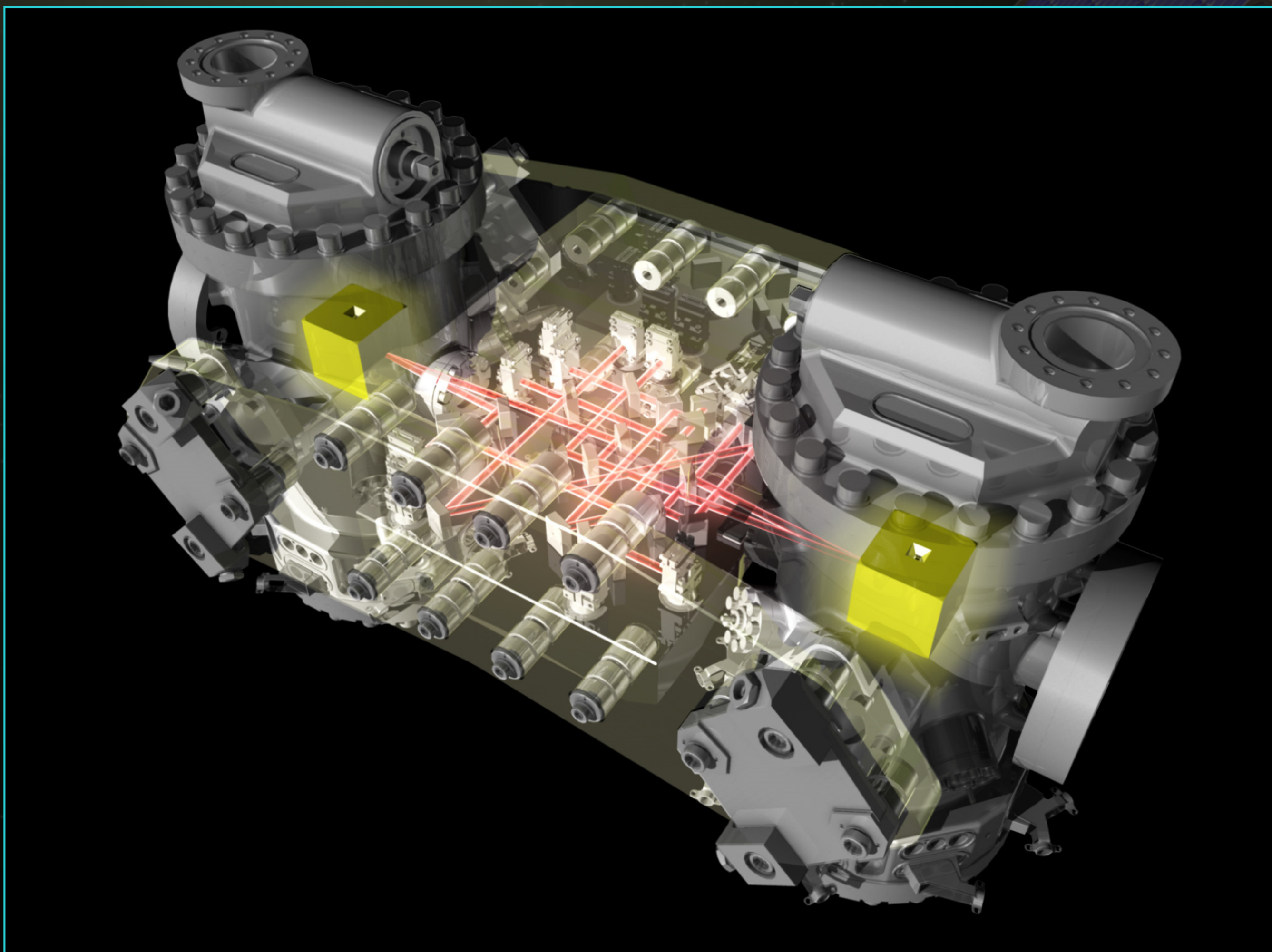
III. LISA

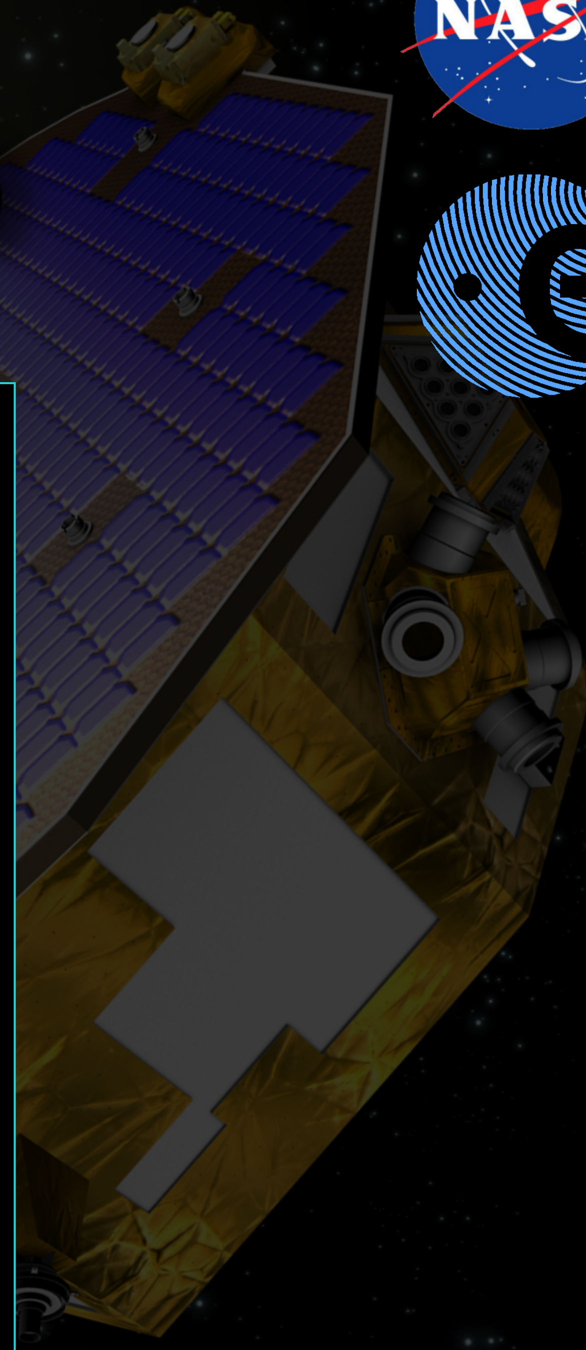


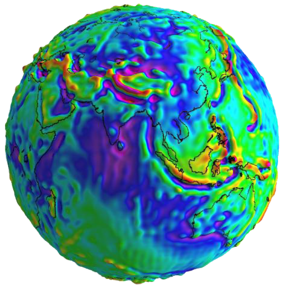




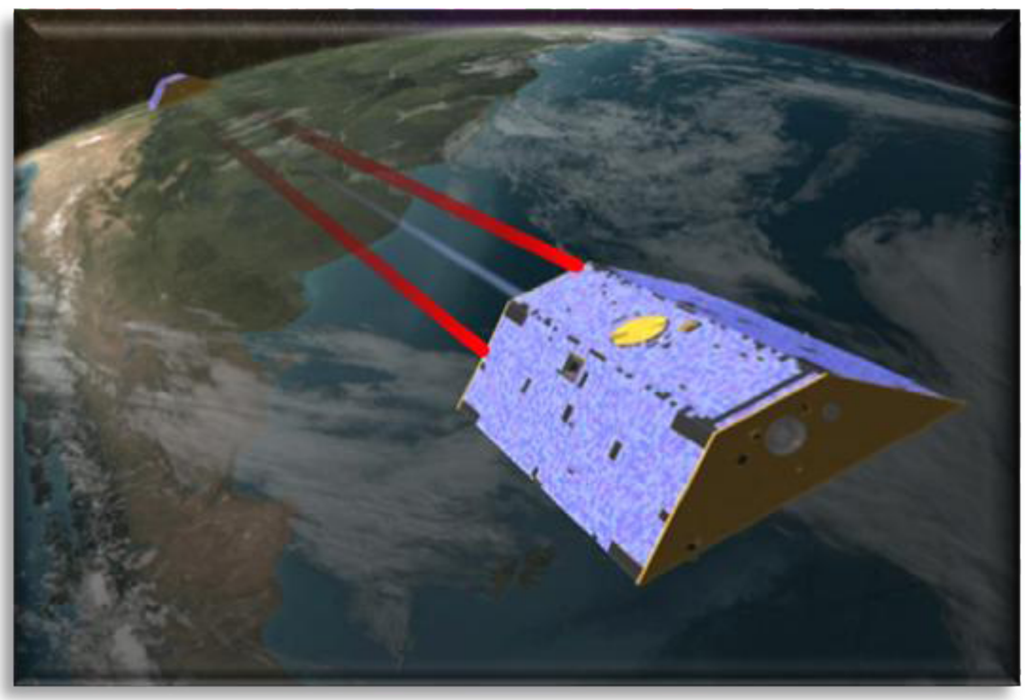
LISA Pathfinder

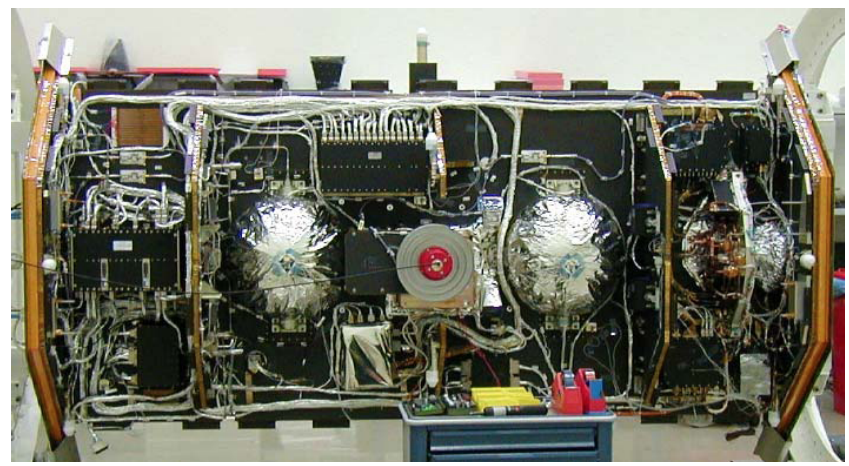


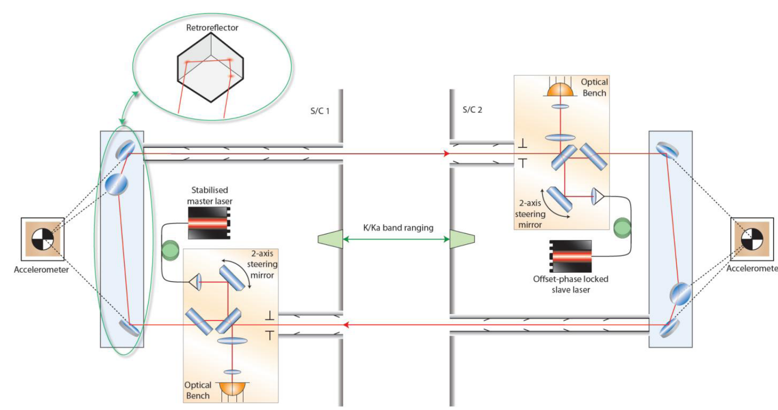




GRACE follow-on
(Launch August 2017)







Key LISA technologies

Free flying test mass subject to very low parasitic forces:

- Drag free control of spacecraft (non-contacting spacecraft)
- Low noise microthruster to implement drag-free
- Large gaps, heavy masses with caging mechanism
- High stability electrical actuation on cross degrees of freedom
- Non contacting discharging of test-masses
- High thermo-mechanical stability of S/C
- Gravitational field cancellation

Precision interferometric, *local* ranging of test-mass and spacecraft:

- pm resolution ranging, sub-mrad alignments
- High stability monolithic optical assemblies

Precision 1 million km spacecraft to spacecraft ranging:

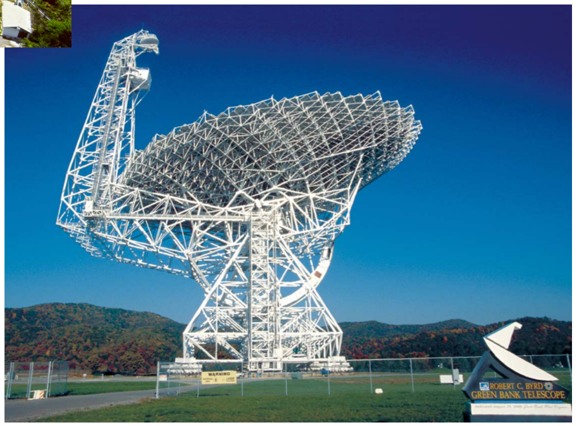
- High stability telescopes
- High accuracy phase-meter
- High accuracy frequency stabilization
- Constellation acquisition
- Precision attitude control of S/C

Elements in red tested by LISA pathfinder

Elements in blue tested by GRACE follow-on

LISA in the Gravitational Wave Era

- Within 5 years or less, LIGO-Virgo and Pulsar Timing Arrays will produce the **first GW catalogs**



- LISA's additions to the GW catalogs amplifies our understanding of the source populations
  - SMBH mass spectrum extends from PTAs to LISA
  - Compact binaries (NS-NS, BH-BH) evolve from LISA band to LIGO band

LISA Cosmology & Fundamental Physics

- GW observations of merging binaries give a direct measure of luminosity distance
- LISA sees MBH mergers over wide range of redshifts for cosmography
- LISA probes the Hubble expansion on large scales, and the dark energy equation of state
- LISA sensitive to cosmological backgrounds
- Tests of gravity

Conclusions

- Gravitational wave astronomy with PTAs and LIGO is happening now

- Many exciting astrophysics, cosmology, and fundamental physics possibilities

- LISA is complementary in some ways and revolutionary in others

- Some problematic budgetary issues