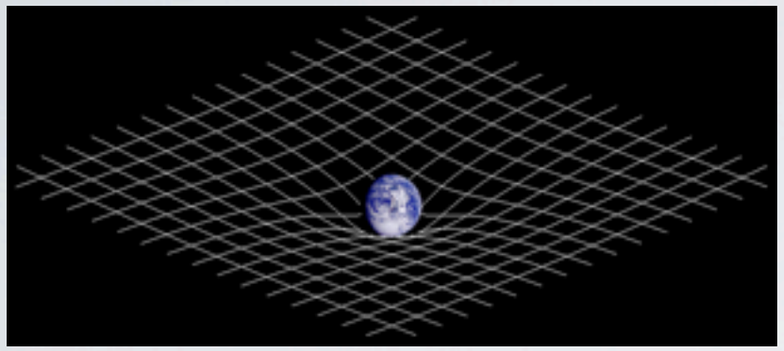
Gravitational Wave Astrophysics and Astronomy in the next decade

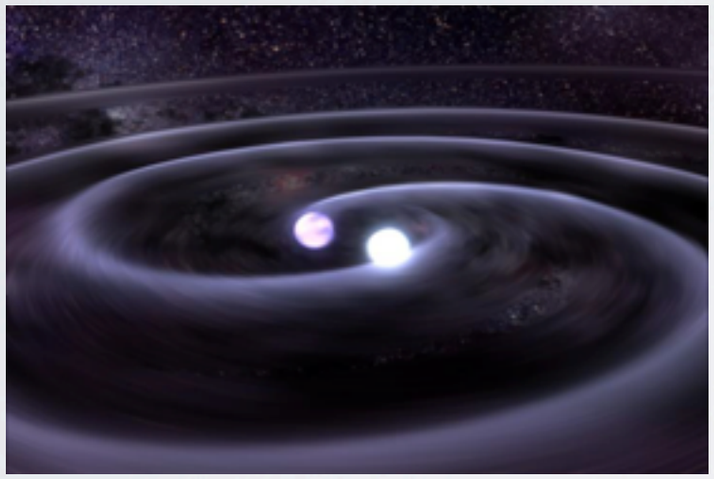
PhysPag@APS April Meeting
Anaheim 2011

Guido Mueller

University of Florida

Gravitational Waves
The sound of the Universe



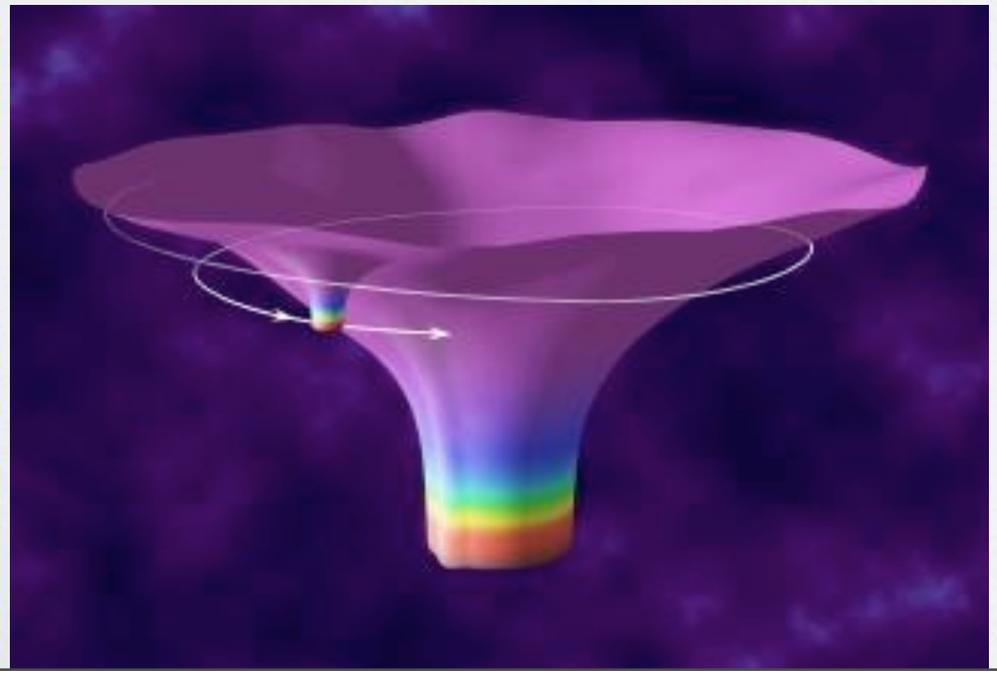


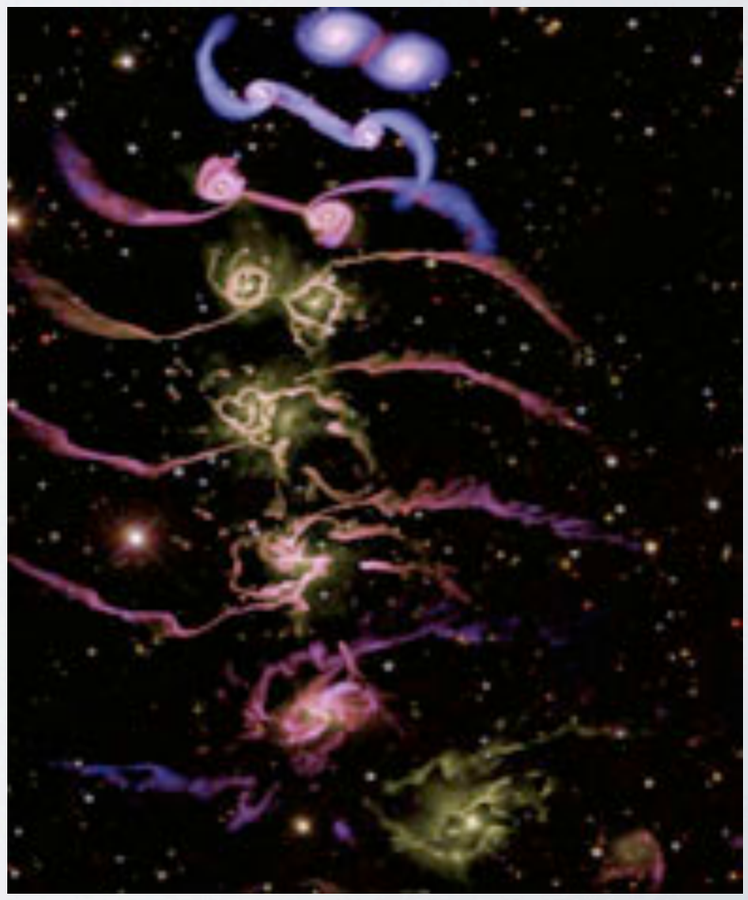
General Relativity:

- Masses tell space how to curve
- Space tells masses how to move

Accelerated masses stir up spacetime

- Gravitational waves
  - Binary systems
  - Supernovae
  - Big Bang
  - ...





Inflation Probe

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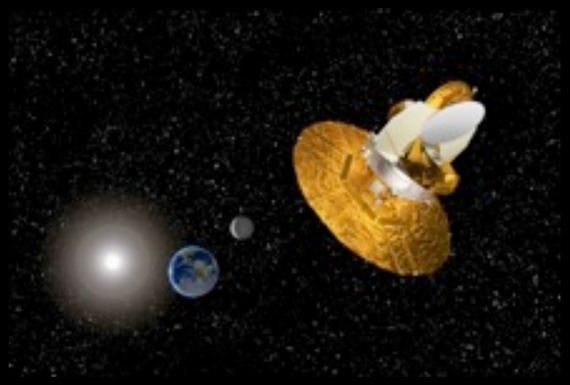


Polarization in μ-Wave Background

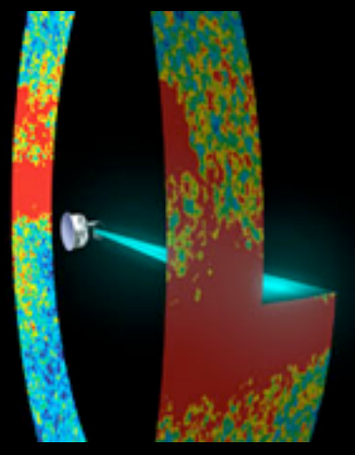
Sources:
Density fluctuations
Gravitational Waves

Science:
Inflation

2020+

Earlier μ-wave missions:

- COBE
- WMAP
- Planck (launched 2009, end of operation 2012/13)
  - Search for primordial GW signatures in the polarization of the μ-Wave background



Pulsar Timing

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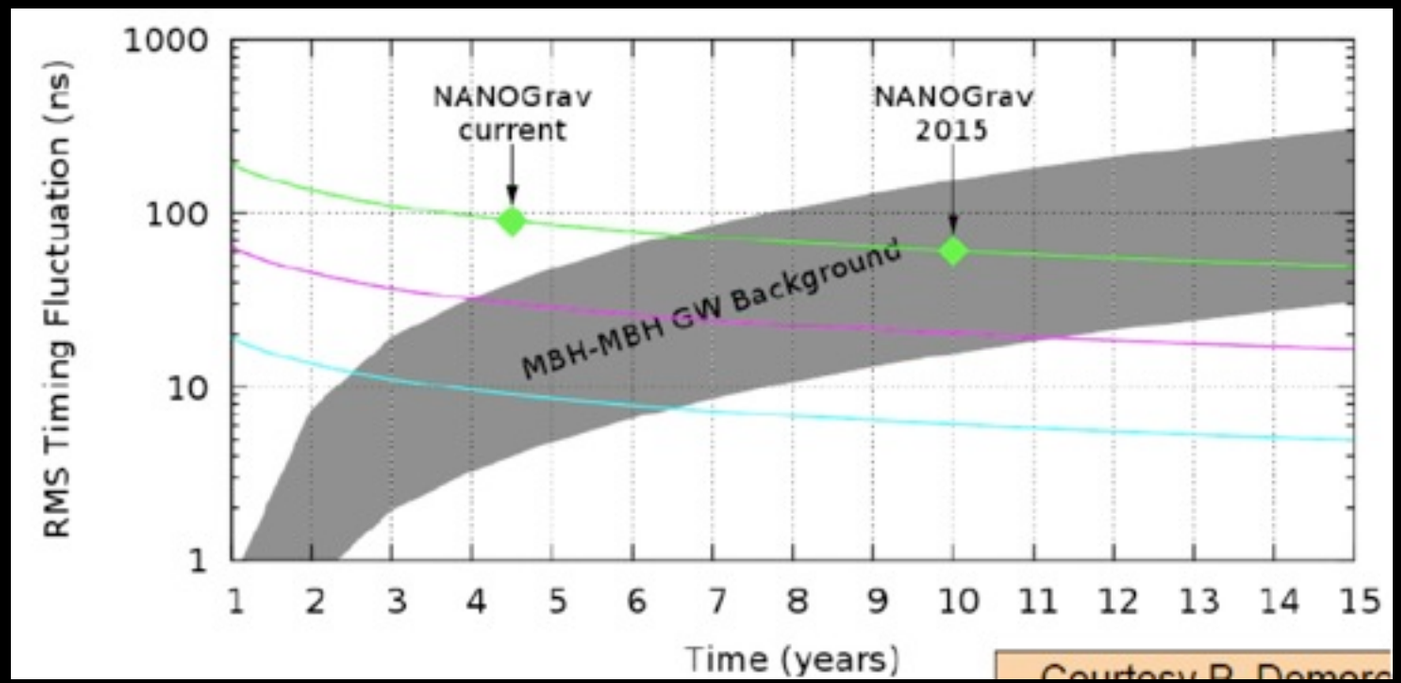


NANOGrav Collaboration

Sources:
MBH-binaries

Science:
Merger rate vs. redshift

Reach critical sensitivity: 2015

Expected GW sources:
Massive BH binaries
- Freq.: nHz - uHz
- Individual Binaries
- Stochastic Background

Technique:
- Timing 26 pulsars
- 100 ns resolution
- Reach critical sensitivity ~2015

Arecibo

Green Banks

Ground-based Gravitational-Wave Detectors

LIGO

LIGO, VIRGO, LCGT

Sources:
NS/BH mergers
Supernovae
Pulsars, ...

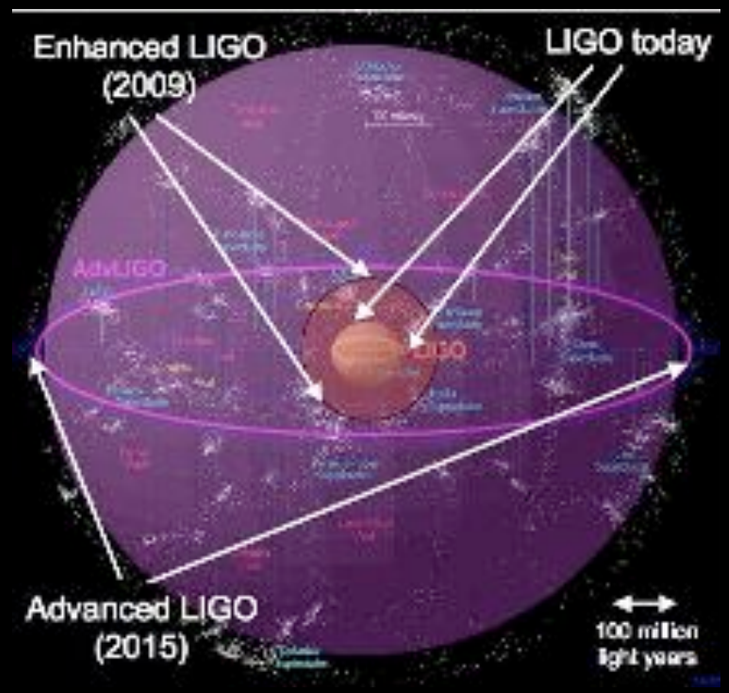
Reach critical sensitivity: 2015

LIGO/eLIGO, VIRGO, GEO:

- 6 Science runs
  - Many upper limits

Advanced LIGO/VIRGO/LCGT:

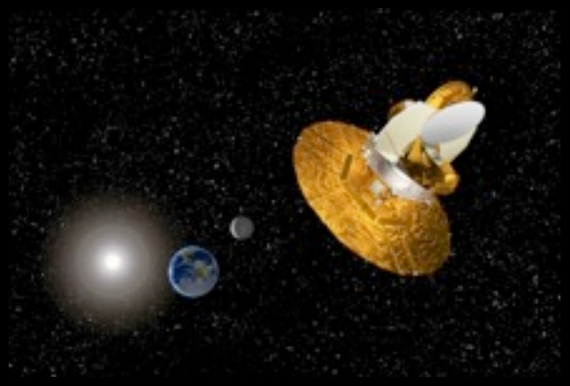
- Construction/Installation started October 2010
- On-schedule and budget for first science runs 2014
- 50-100MPc, 50% duty cycle
- 140MPc by 2016
- Full sensitivity 2018



GEO continues running at least until 2015

Promising GW-Detection schemes/Detectors

Inflation Probe



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Source: Density Fluctuations Gravitational Waves

2020+

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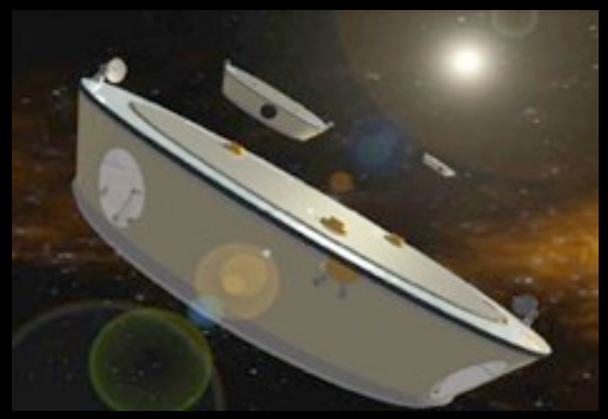
Reach critical sensitivity: 2015

-18 **-15** **-9** **-6** **-5** **-1** **1** **4**

f [log Hz]

Most promising GW-Detector

LISA

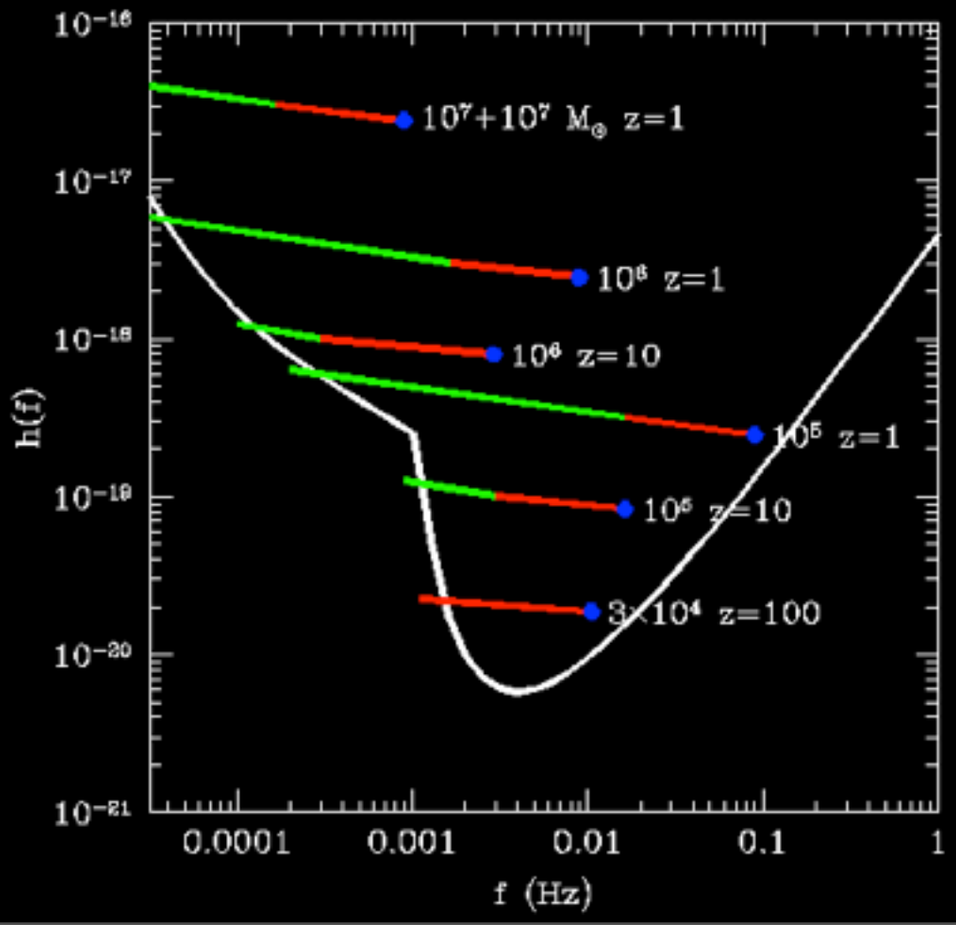


Former joint
NASA/ESA project

Sources:
SMBH mergers
EMRIs
Galactic binaries

Guaranteed signals
Largest SNR
Most Science

- **Super Massive Black Holes**
  - **How did they grow?**
  - **When did they grow?**
  - **Role in Galaxy formation?**
  - **Precision tests of strong-field gravity**



- **Estimated SMBH merger rates:**
  - **1/week**
- **SNR: 10-10000!**

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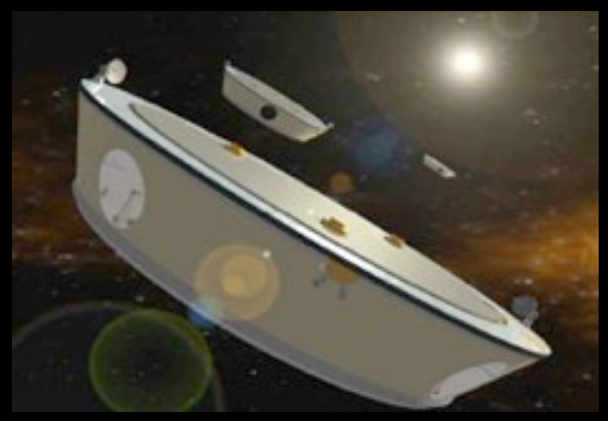
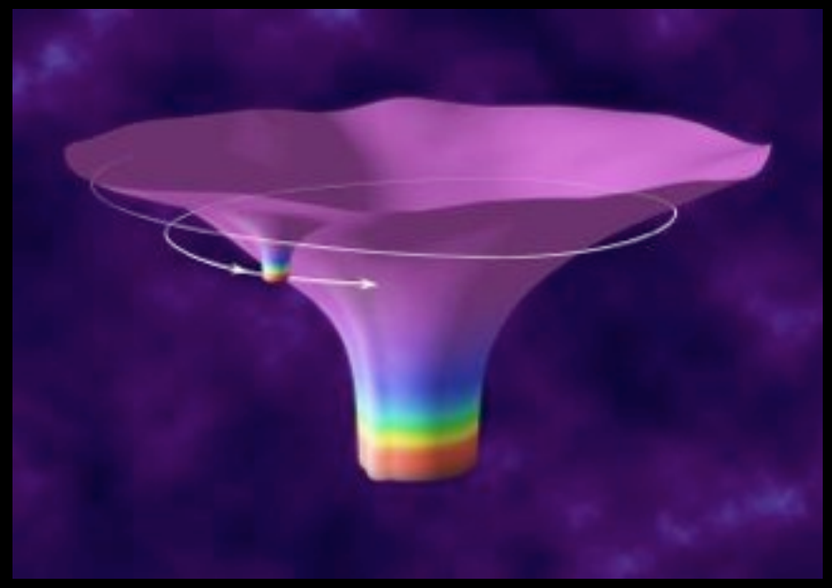


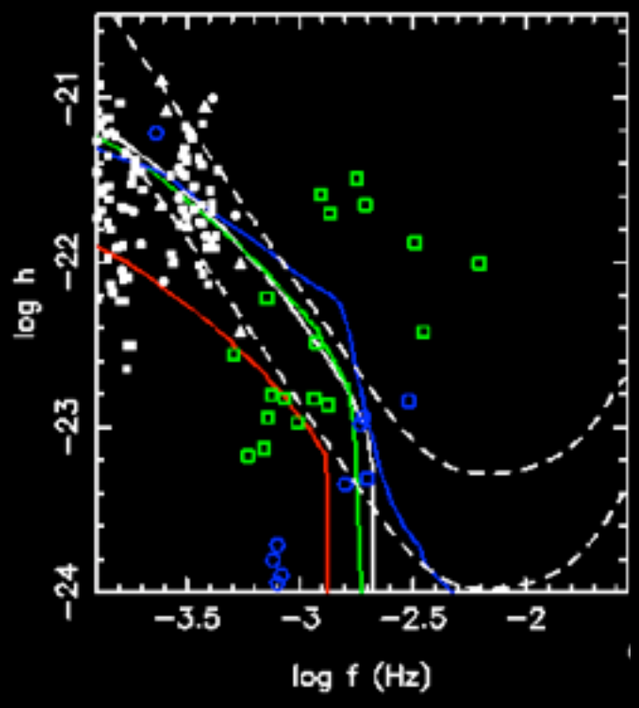
Former NASA/ESA project

Extreme Mass Ratio Inspirals (EMRIs):

1-10 M_θ compact object falling in a 10^4-$10^7 M_\theta$ BH

- Test particle case for GR
- Rate betw. 5-500/year





Galactic Binaries

- Galactic BH/NS/WD binaries
- 5-10 Verification binaries (**guaranteed** sources!)
- Expect ~10,000 individual binaries
- Stochastic background from > 100,000 binaries
- ...

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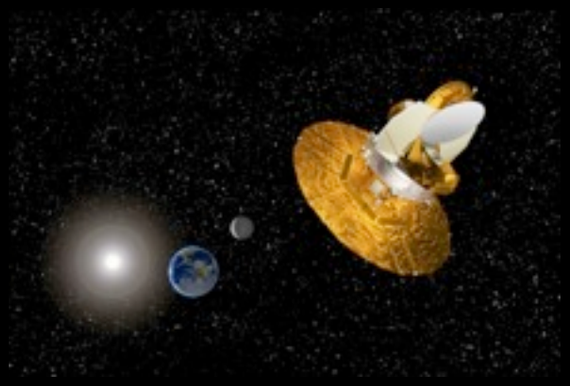

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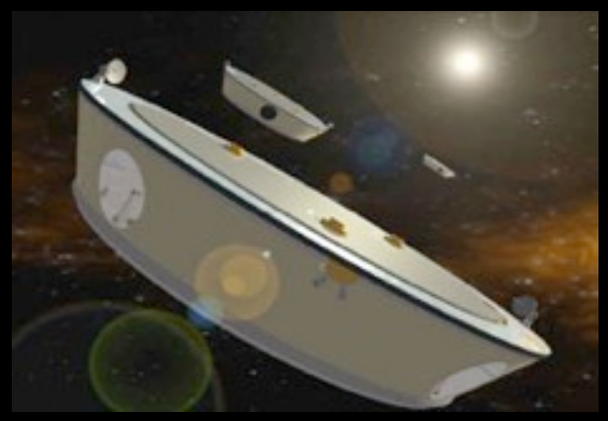

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f [log Hz]

Most promising GW-Detector

LISA:

- joint ESA/NASA Project 1995-2011
- European/US Science Team (LIST)
- Highly endorsed by all scientific reviews over last 10+ years
- LISA Pathfinder will test Gravitational Reference Sensor in 2014/15
- LISA Interferometry fully developed and tested
- Mature mission design
  - System level design required for subsystems:
    - 2W-Laser, Telescopes, Articulation mechanism, ...

Reviews realized high TRL status after successful operation of Pathfinder

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Status February 2011

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Future of Space-based GW-Observatories

NASA:

- No funding to support 2020 LISA launch
  (or any other large mission except JWST)

ESA:

- Has funding for L-class mission (launch 2020)
- Three candidates:
  - Laplace
  - IXO
  - LISA
- Develop re-scoped mission concepts until end of this year
- February 2012 selection by ESA Science Programme Committee

Future of Space-based GW-Observatories

ESA:

- L-Class budget: 850M Euros
  + Member contributions (~300M)
  + Potential external junior partner(s)

- Note: ESA cost accounting very different from NASA
  - Results in lower overall mission costs
  - ESA cost estimate for current LISA design: 1.3B Euro (NASA: $2.4B)

LISA-like missions:

- Difficult to cost (No real experience with this type of mission)
- Main cost driver: Orbits (Mass, S/C Size, Distance)

Future of Space-based GW-Observatories

The last 3 months:

ESA:

- Established European Science Team
  - NASA represented by Robin 'Tuck' Stebbins (GSFC) (Robin.T.Stebbins@nasa.gov)
- Former US-LIST members (N. Cornish, M. Vallisnieri, ...) continue to work with European colleagues on science analysis
  - https://lisa-light.aei.mpg.de/

NASA continues R&D on GW-missions

- To support ESA-led mission
- To develop concept for NASA-led future mission

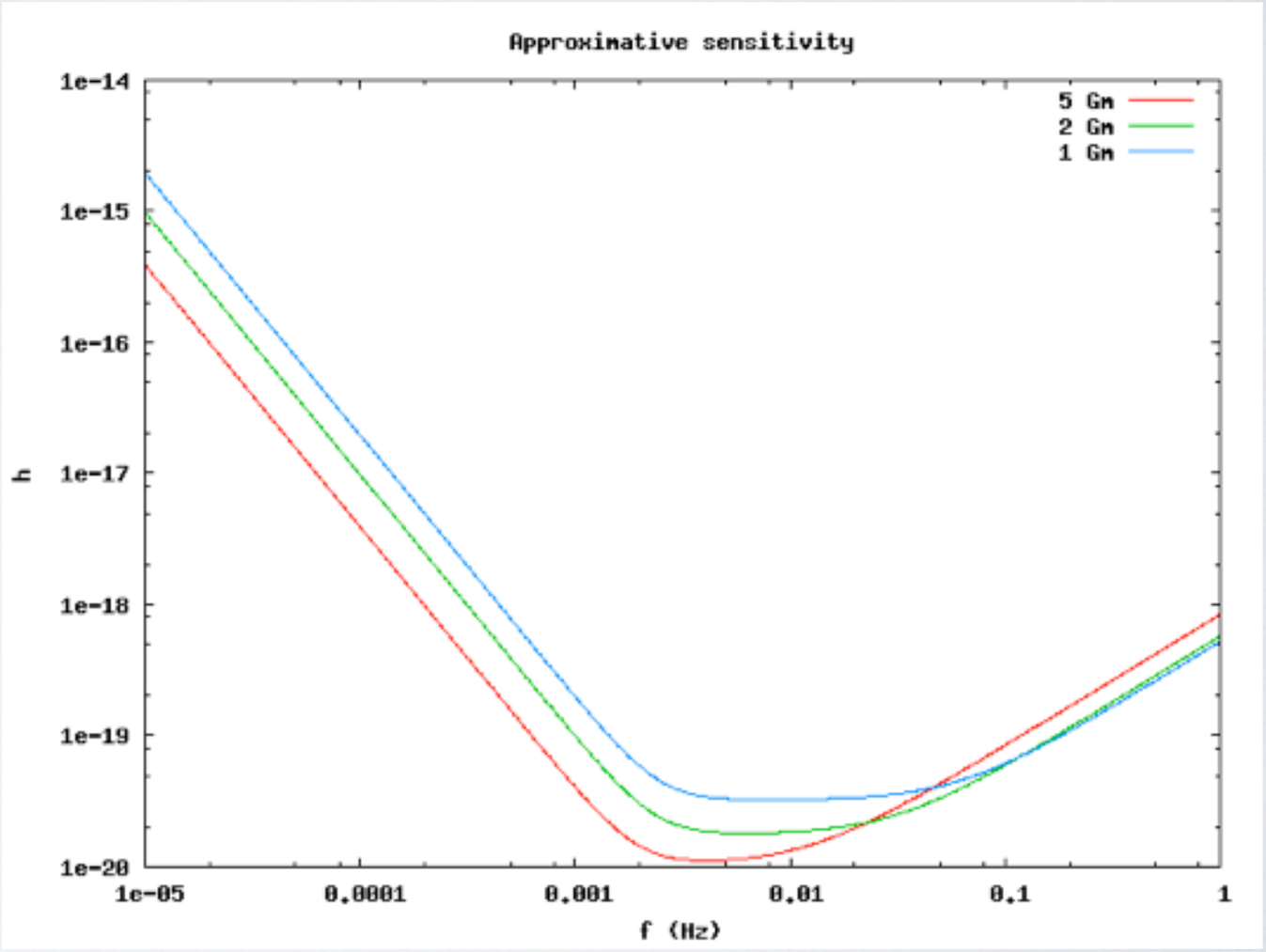
Current ESA study

- New orbits
  - Launch cost
  - relative velocities
  - Lifetime of constellation

- Smaller telescopes
  - Reduces size and mass

- Laser power
  - Power consumption
  - Shot Noise sensitivity

- Science impact
  - SMBH-mergers
  - EMRI's
  - Galactic Binaries



LISA and Changes in the Cosmic Vision Programme

Based on discussions with the European Space Agency (ESA) at the recent ESANASA bilateral meeting, we provide the following information concerning LISA. Readers are advised to refer to any ESA postings - when available - for details and clarifications regarding the Cosmic Vision Programme.

LISA was competing with x-ray and outer-planets missions for the L1 opportunity in ESA's Cosmic Vision Programme (2015-2025). The decadal rankings and NASA's constrained out-year resources, projected in the President's FY12 Budget Request, led ESA to conclude that none of the three mission concepts were feasible within the Cosmic Vision L1 schedule.

ESA has ended the study of LISA and the other concepts as partnerships at the scale proposed in the New Worlds New Horizons decadal survey (NWNH). ESA has begun a rapid definition effort that includes the formation of a new science team (to be announced shortly). That effort will identify science goals and a mission concept that can be implemented as part of an ESA-led mission launching in the early 2020's. Revised mission concepts from the three science areas will be considered in a selection process commencing in February 2012.

A future minor role for NASA in the ESA-led mission has not been ruled out. NASA will participate in the new ESA science team through a "NASA-HQ empowered scientist." That representative will be a civil servant scientist who will act as conduit for input from and information to the US science community.

NASA's Astrophysics Division plans to continue base funding for the LISA study team through FY11, assuming not-larger-than-anticipated cuts from Congress. The Division will engage the community about strategic investments in gravitational wave astrophysics and possible solicitations for new concept studies, in the context of NWNH recommendations and projected resources. A US science team will be asked to provide input from the community on the way forward in gravitational wave astronomy including scientific and technical assessments.

from R. Stebbins

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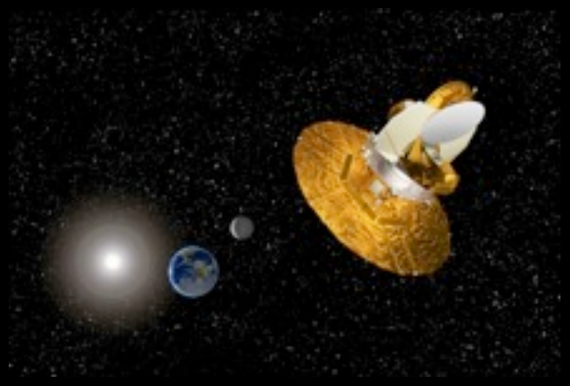

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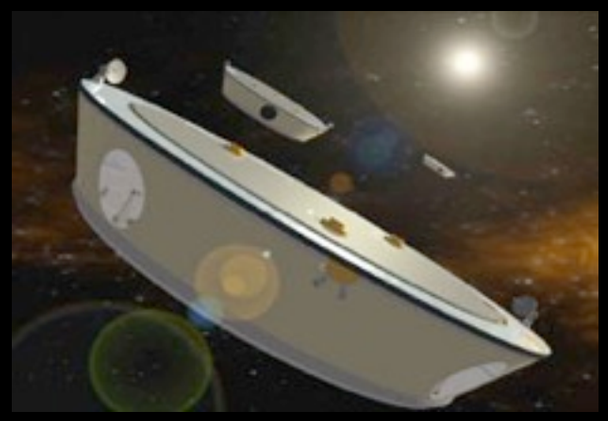

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f [log Hz]

The next years:

- **Develop experiments for Pathfinder**
  - **Need to get as much science out of pathfinder as possible**

- **If ESA selects a GW-mission, NASA should support it with**
  - **R&D in US (Technology, Science Case, Data Analysis)**
  - **Identify funds to join ESA as junior partner**
  - **Identify subsystems NASA could deliver**

- **Develop capabilities to fly own GW-mission in future**
  - **Lower frequencies**
  - **Lower shot noise (GW-background, BBO-type??)**

Specific Technologies which NASA could develop or continue to develop:

- **Colloidal thrusters:**
  - **Have been developed for LISA Pathfinder but need increased lifetime testing for LISA**
- **Telescope structure**
  - **Stability (active or passive)**
  - **Scatter**
- **Lasers & Optics**
  - **Power, Lifetime, Actuation, Modulation, Detectors, ...**
- **Phasemeter**
  - **Lower noise, larger bandwidth**
- **...**