LIGO G1300908

LIGO
LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY

Stochastic Gravitational Waves in the Advanced Detector Era

Eric Thrane (Caltech)
for the LSC and Virgo

TAUP 2013, Asilomar

VIRGO

Stochastic backgrounds from superposition

- Gravitational-wave strain signals can be represented as audio.
- A stochastic background = superposition of many GW signals too faint to detect individually.

BNS chirp

high duty cycle: 100x

popcorn signal

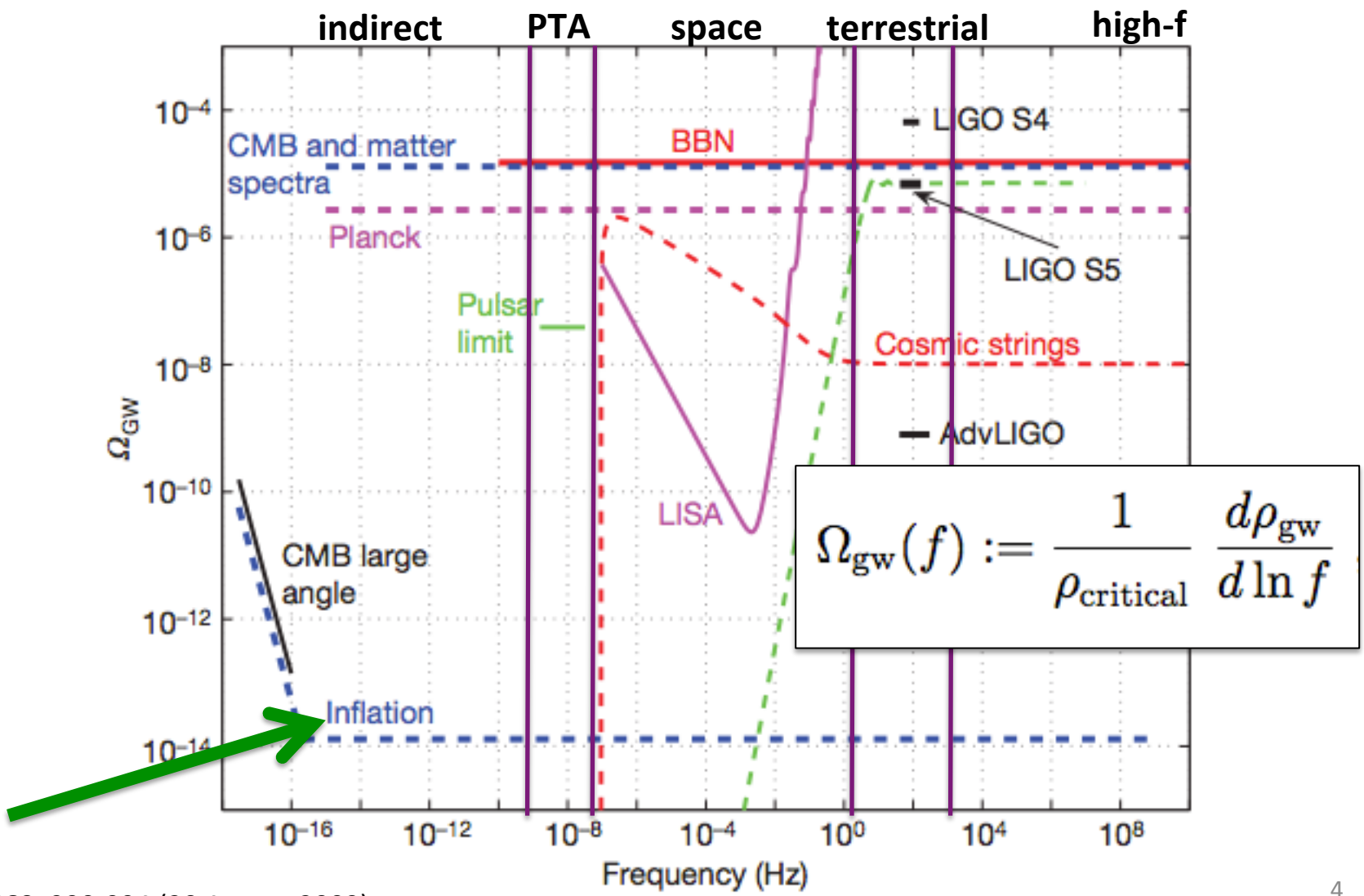
Gaussian noise

Stochastic sources

- **Astrophysical signals** from "ordinary" objects like neutron stars and black holes in more recent universe.
- **Cosmological signals** from major life events in the history of the universe, e.g., phase transitions, cosmic strings, etc..
- **The Holy Grail (fundamental physics):** e.g., amplifications of vacuum fluctuations at inflation, probably very hard to detect, but chance to probe $E=10^{15}$GeV.

SGWB plotter: http://homepages.spa.umn.edu/~gwplotter/

Ω(f) spectrum



$$\Omega_{\rm gw}(f) := \frac{1}{\rho_{\rm critical}} \frac{d\rho_{\rm gw}}{d\ln f}$$

Nature **460**, 990-994 (20 August 2009)

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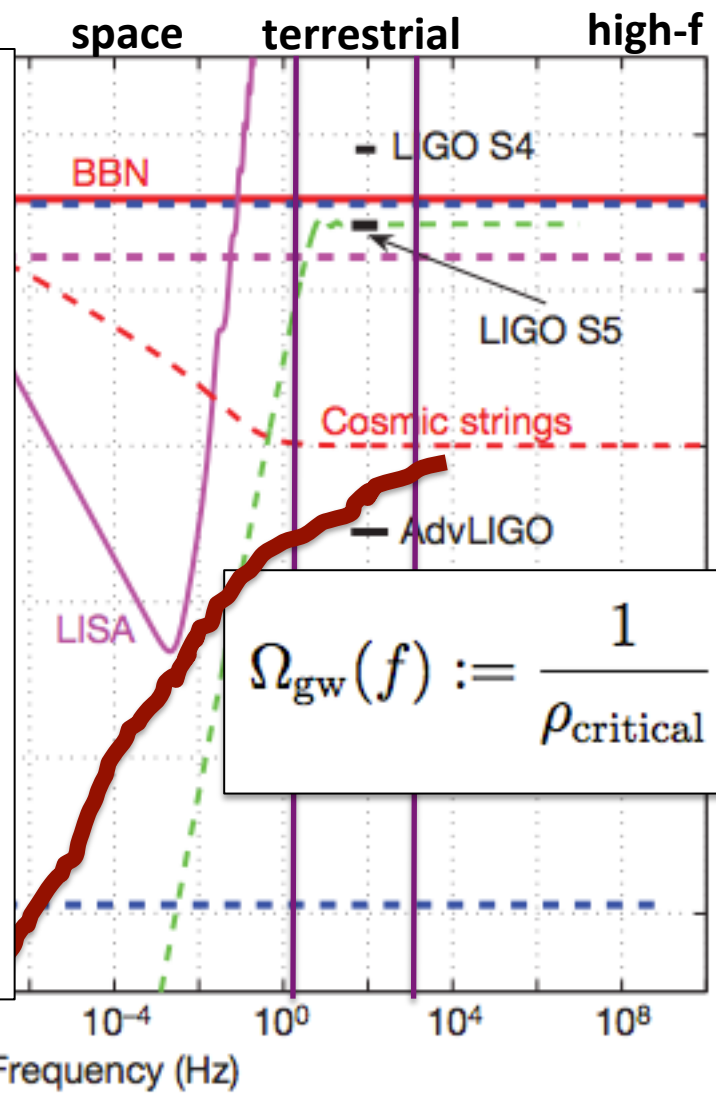
- Axion production →inflationary GW signals detectable by aLIGO corresponding to energies of 10^{17} GeV, see:
  - Cook J and Sorbo L, *Phys. Rev. D* **83** 023534 (2012)
  - Barnaby N *et al.*, Phys. Rev. D **85** 023525 (2012)



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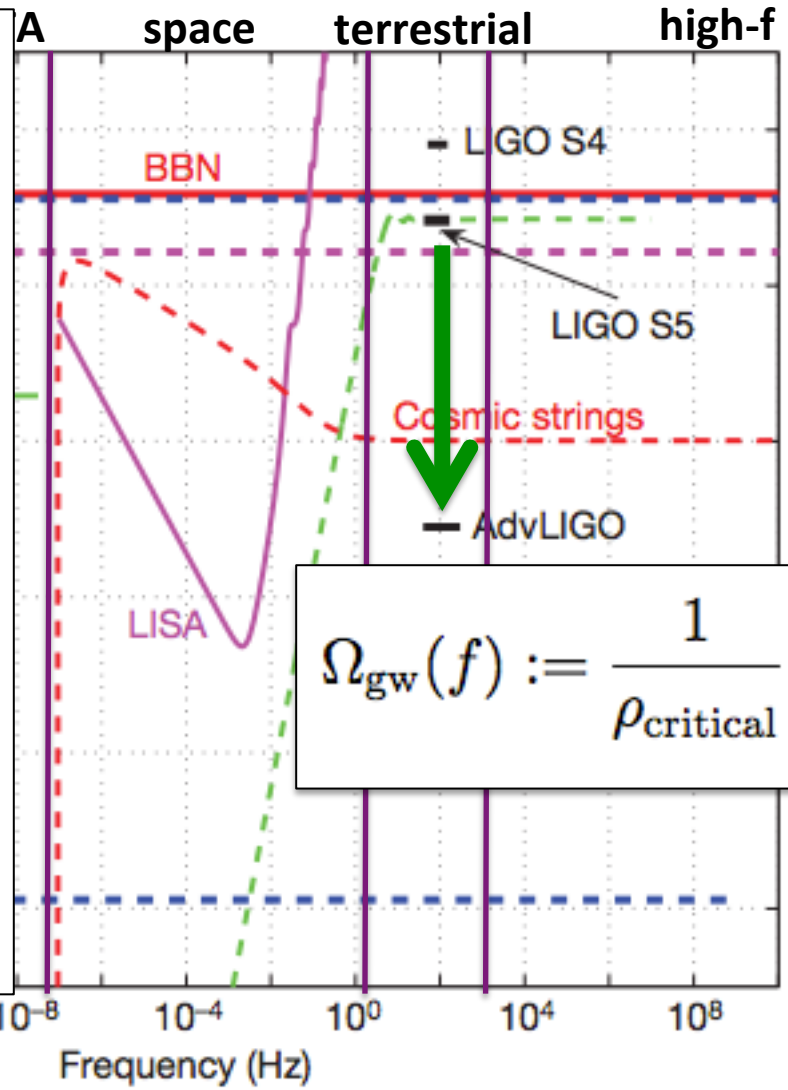
Ω(f) spectrum

- Initial LIGO: $\Omega_{GW}<6.9\times10^{-6}$ between 40–500 Hz.
- For aLIGO: ~10^4x improvement from 10x better strain sensitivity and f_{min}= 40Hz→10Hz



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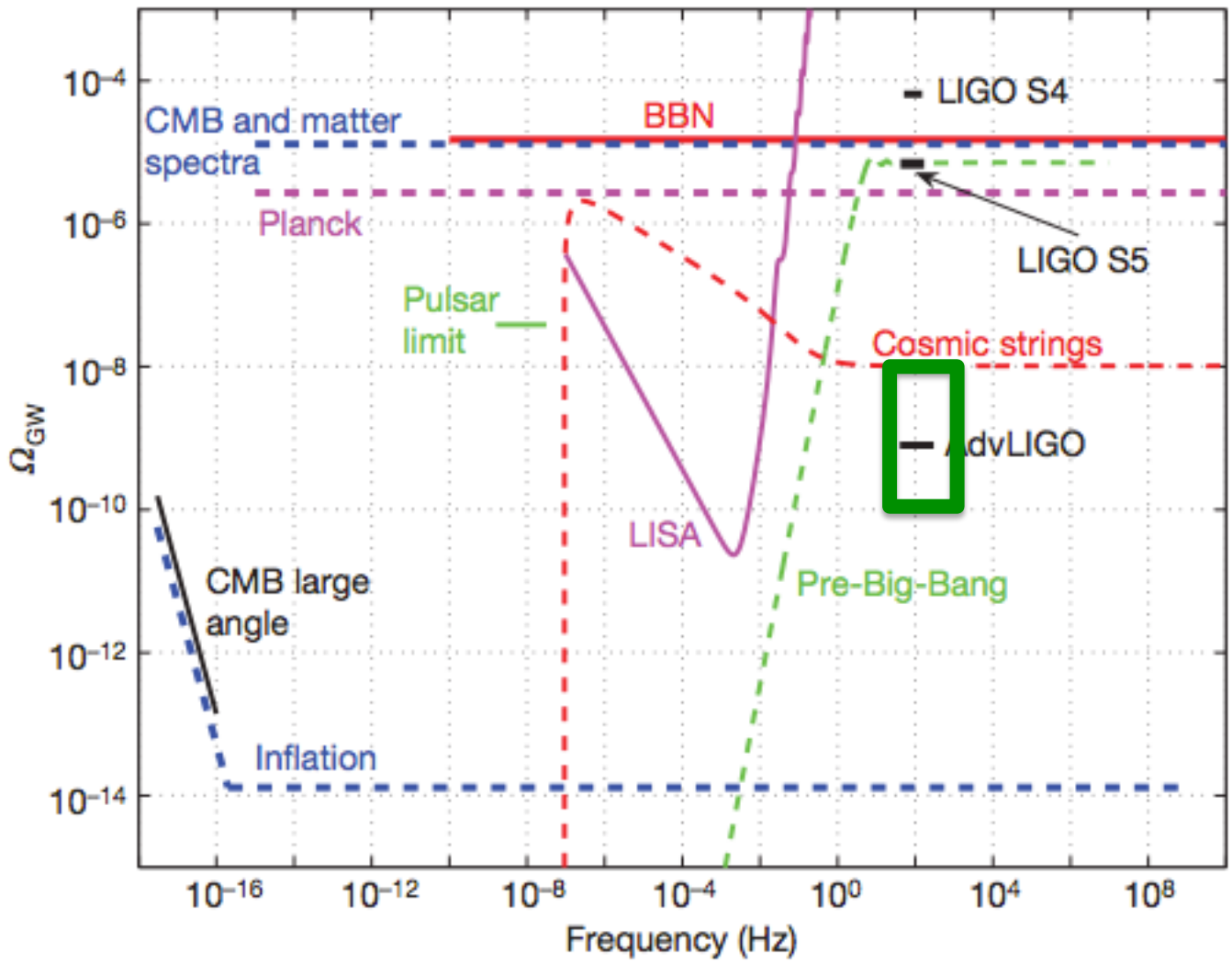
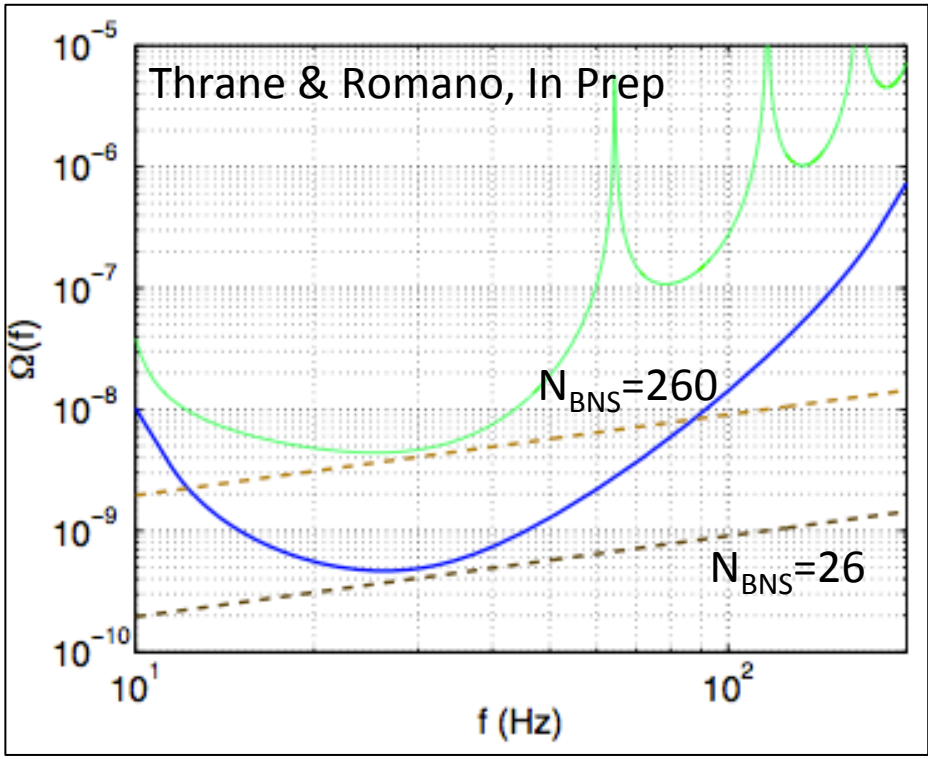

CMB and matter spectra
BBN
LIGO S4
Planck
LIGO S5
Pulsar limit
Cosmic strings
AdvLIGO
LISA
Pre-Big-Bang
CMB large angle
Inflation
Ω_{GW}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-12}
10^{-8}
10^{-4}
10^{0}
10^{4}
10^{8}
Frequency (Hz)

Detection is a very real possibility!

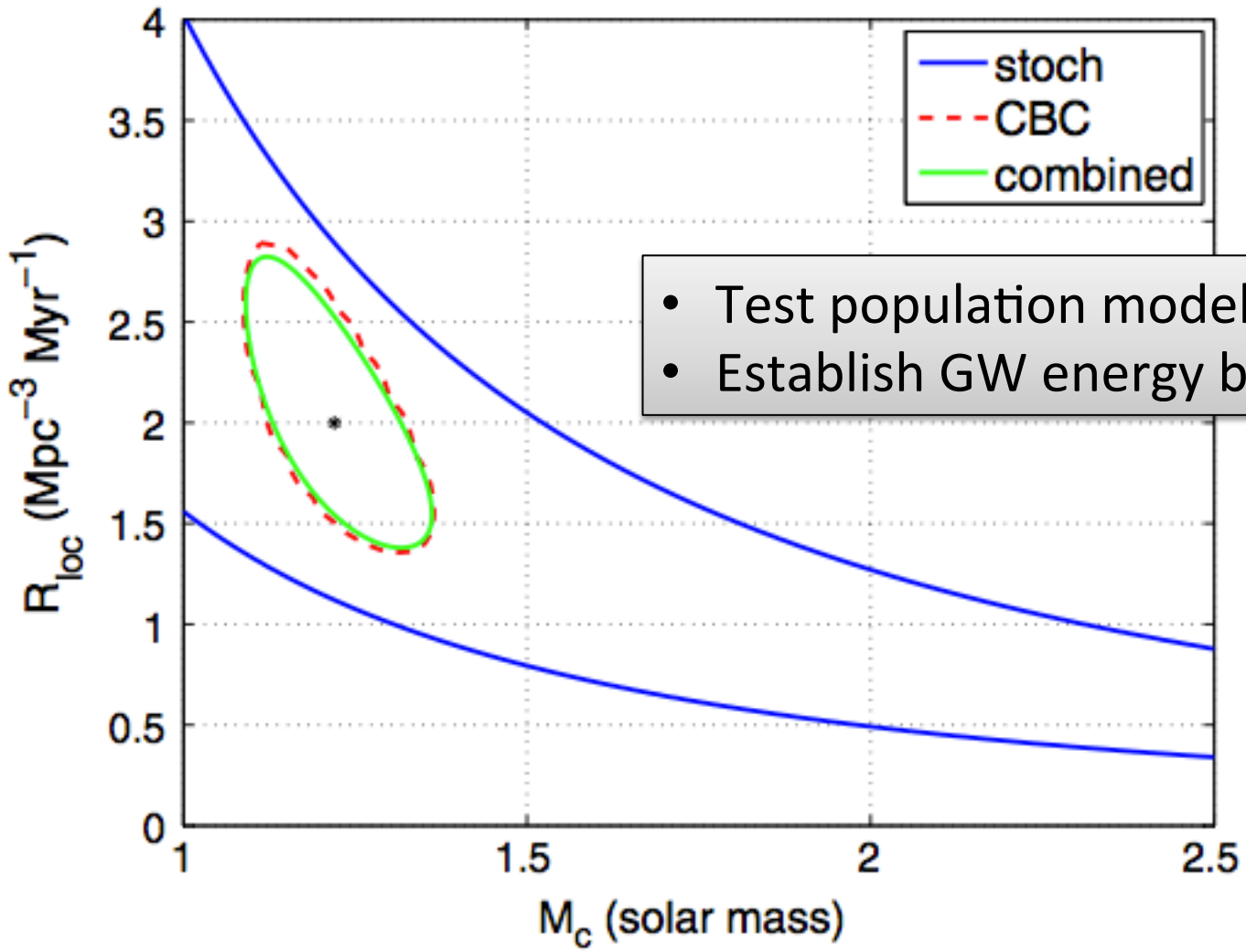
- Given realistic compact binary detection rates (~40 yr^{-1}), detection of an astrophysical background is possible with aLIGO.
- Significant theoretical uncertainties.
- How do we know the origin of a signal…?



Assumes design sensitivity: ~2017–2019.

J Abadie et al 2010 Class. Quantum Grav. 27 173001

Compare with transient detections



- Test population model.
- Establish GW energy budget.

Mandic, Thrane, Giampanis, & Regimbau, PRL 109, 171102 (2012)

Stochastic search

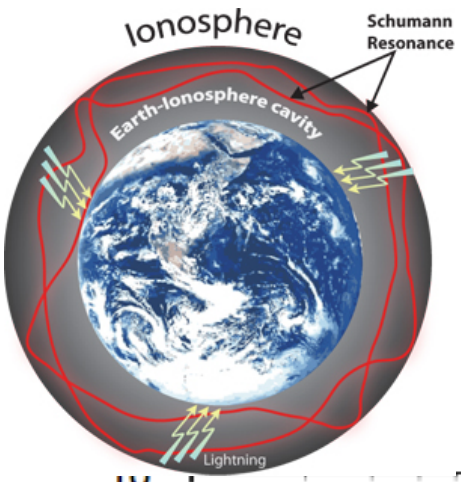
- Goal: measure $\Omega_{GW}(f)$.
- Signal is weak and the time series is unknown.
- In each detector, measured strain series is a sum of signal + noise:

  $s_1(t) = h_1(t) + n_1(t)$

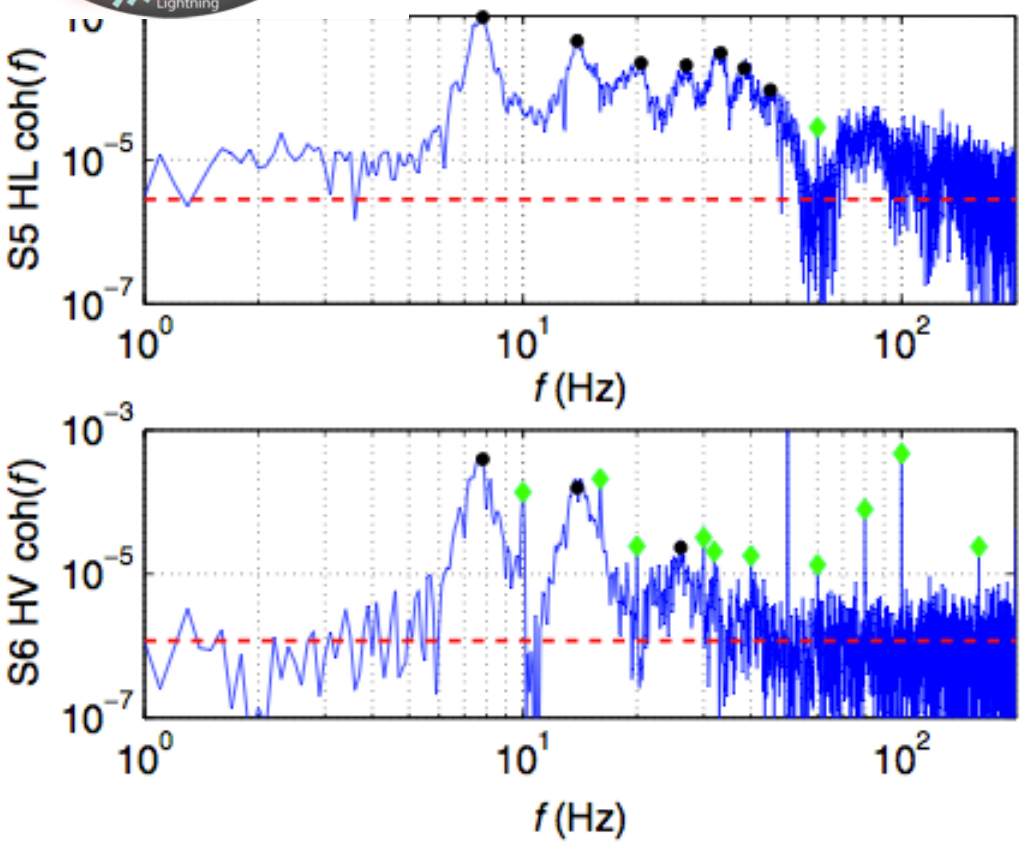
  $s_2(t) = h_2(t) + n_2(t)$
- Solution: correlate ≥2 detectors

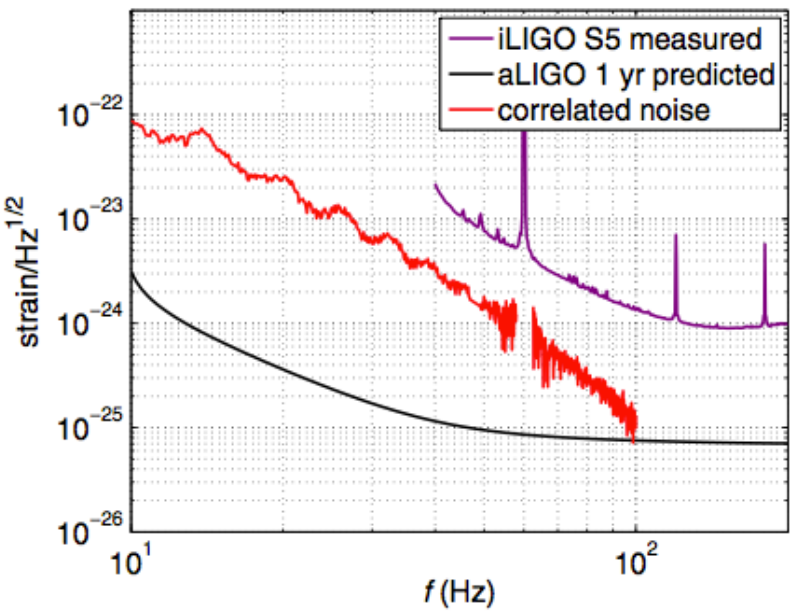
$$Y(f) \propto \frac{1}{N}\sum_{t=1}^{N} \tilde{s}_1^*(f;t)\tilde{s}_2(f;t) = \Omega_{GW}(f) + \Omega_N(f)$$

correlated noise



Correlated noise from Schumann resonances





$$\left\langle \tilde{n}_1^*(f)\tilde{n}_2(f) \right\rangle = \Omega_{noise}$$

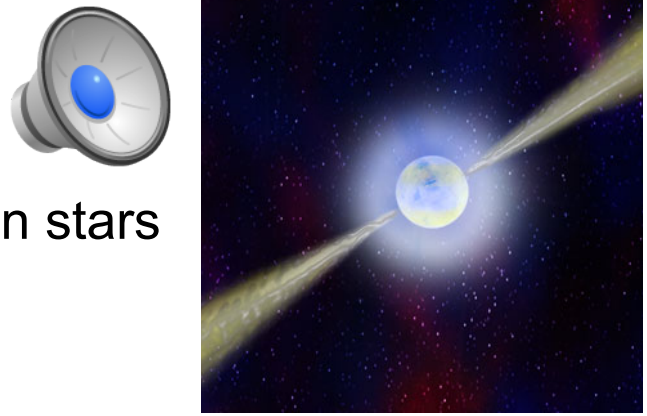
Thrane, Christensen, Schofield, Phys. Rev. D 87, 123009 (2013)

Conclusions

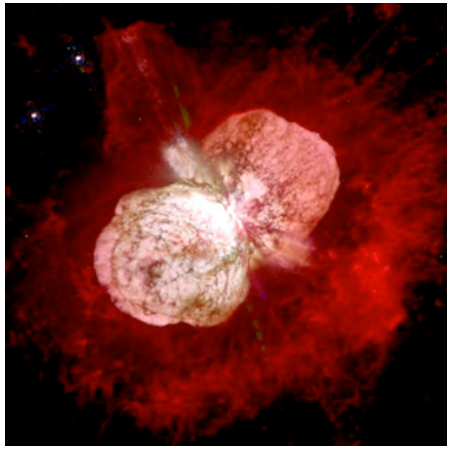
- Real chance of detection of an astrophysical stochastic background with aLIGO + aVirgo.
- Possibility of surprises.
- Work in progress in LV stochastic group:
  - characterize and mitigate correlated noise
  - develop realistic mock data for testing and validation
  - investigate the detectability of different sources
  - explore new ideas, e.g., measuring non-Gaussianity
  - results from S5H1H2 and S6-VSR23 (stay tuned)
  - enhanced directional analyses, e.g., Sco X-1…

Extra slides

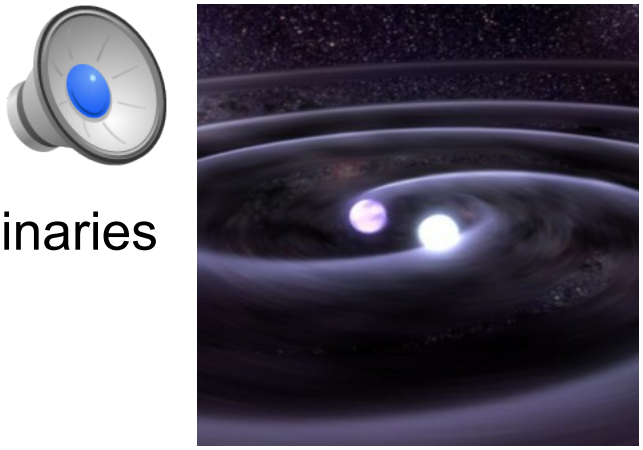
Different gravitational-wave signals



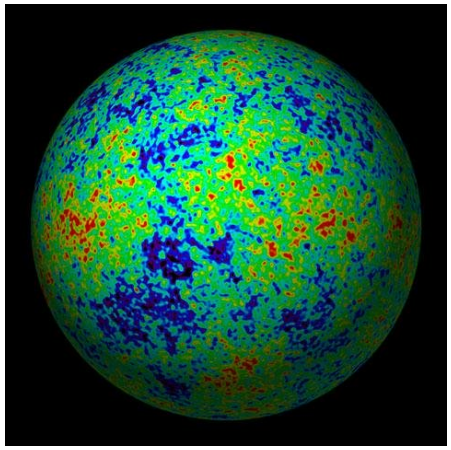
neutron stars



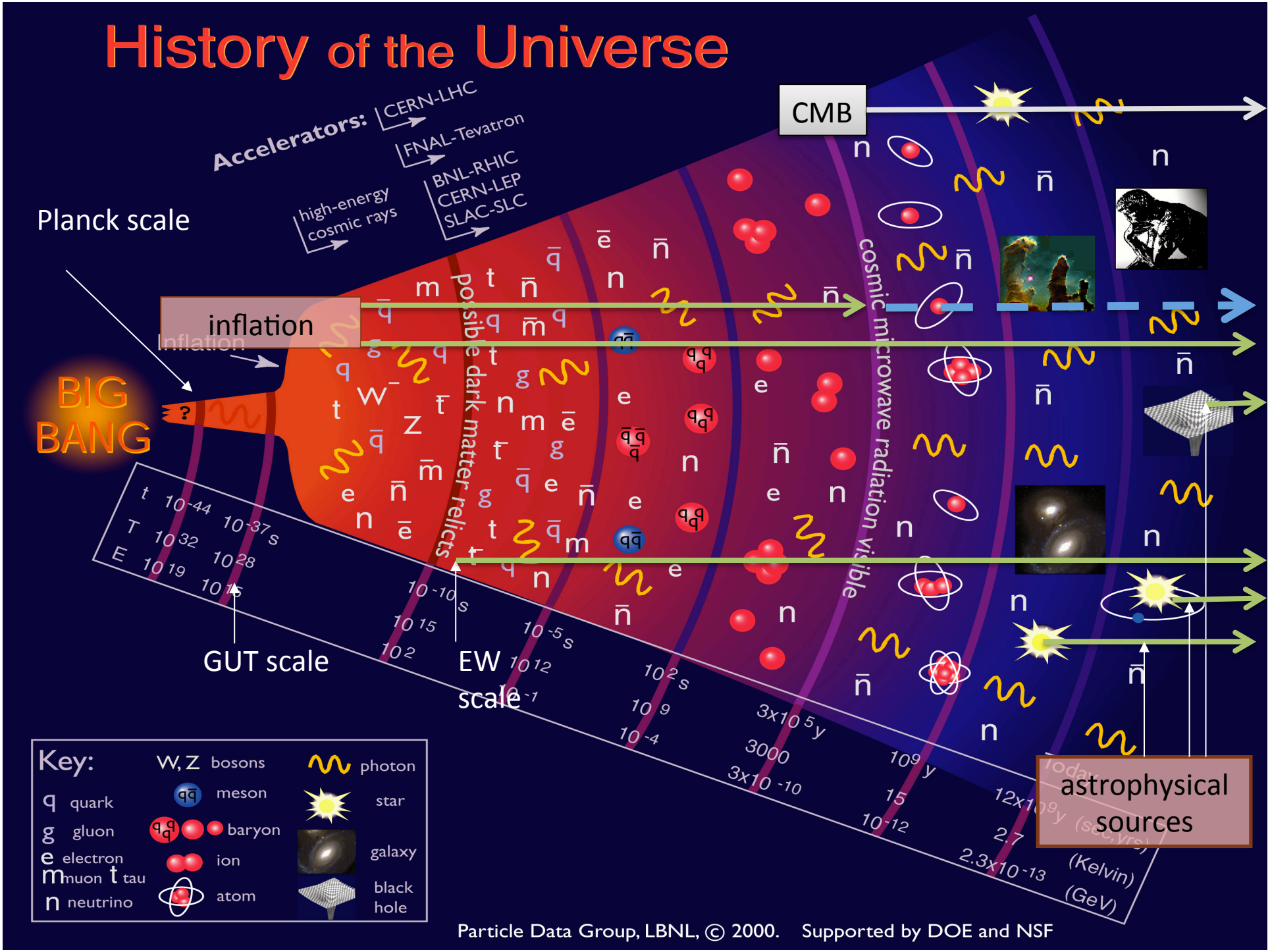
bursts



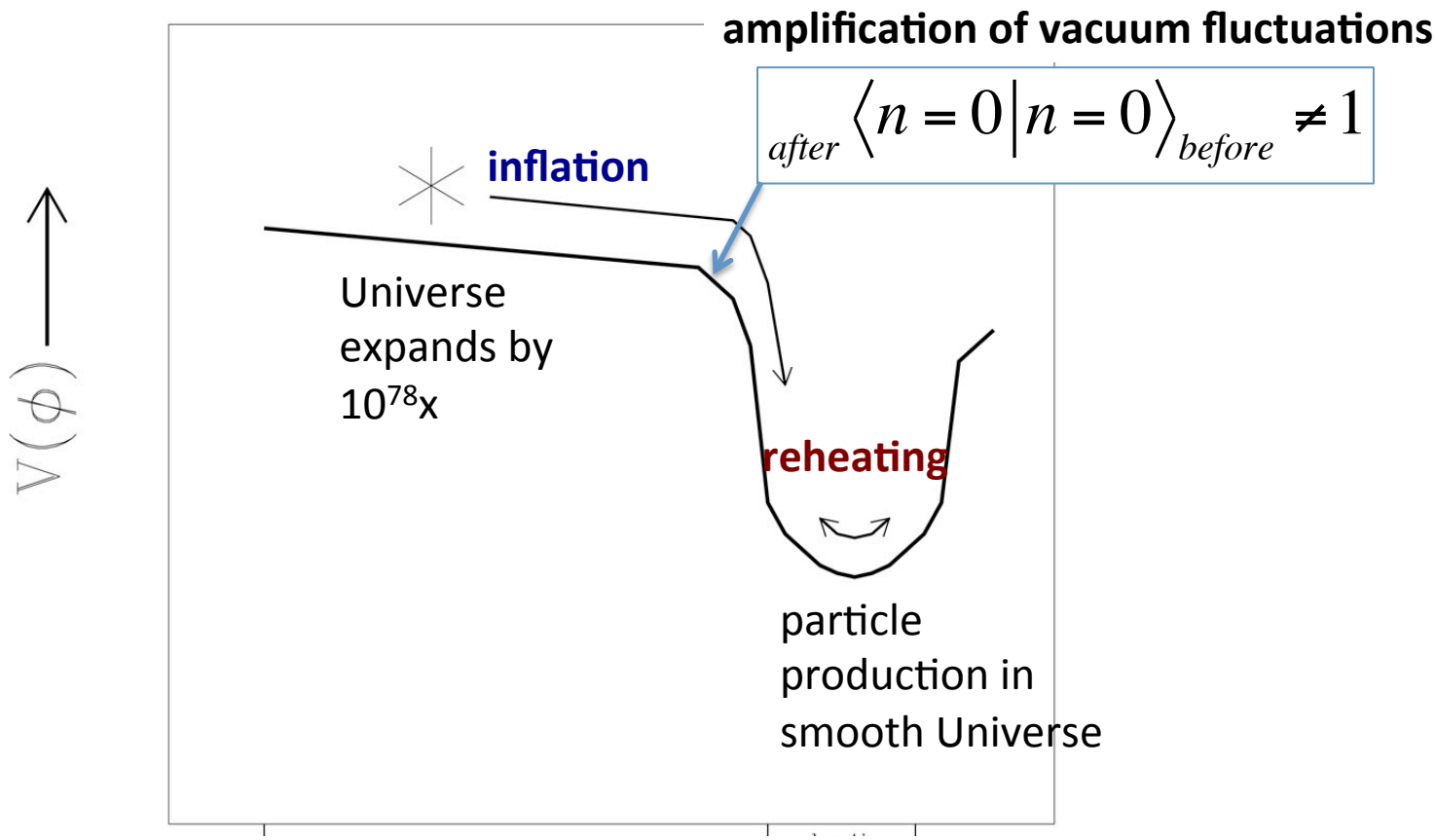
binaries



stochastic


History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Planck scale
CMB
inflation
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
GUT scale
EW scale
astrophysical sources
Key:
q quark
g gluon
e electron
m muon
t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
(Kelvin)
(GeV)
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

Inflation

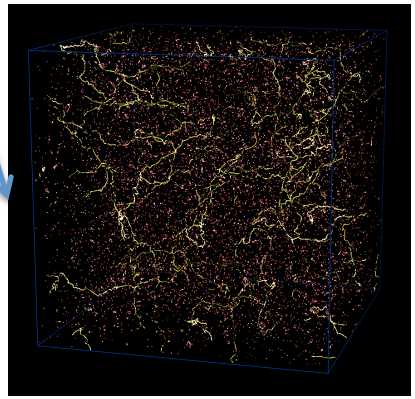


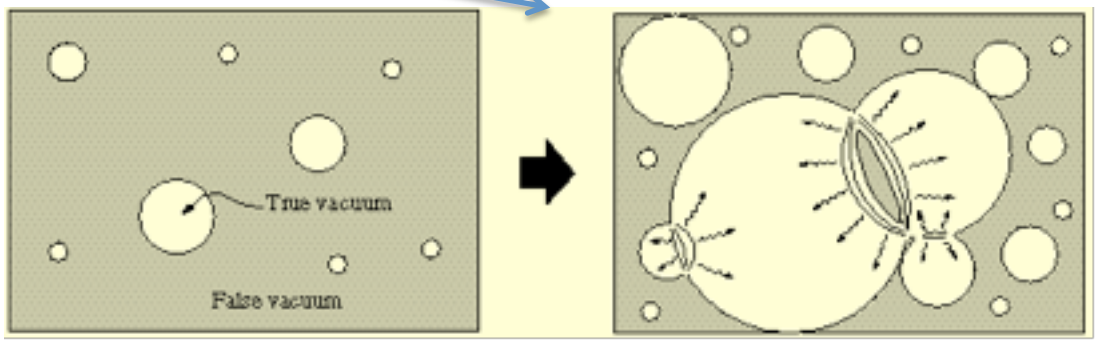
10^{15} GeV: can not test in the lab!

http://ned.ipac.caltech.edu/level5/March03/Lineweaver/Figures/figure8.jpg

Other cosmological sources

- Preheating
  - Inflaton decays through parametric resonance
- Reheating / phase transitions
  - E.g., bubble collisions
- Cosmic strings





See http://arxiv.org/abs/gr-qc/9909001 by M Maggiore

Non-standard inflation

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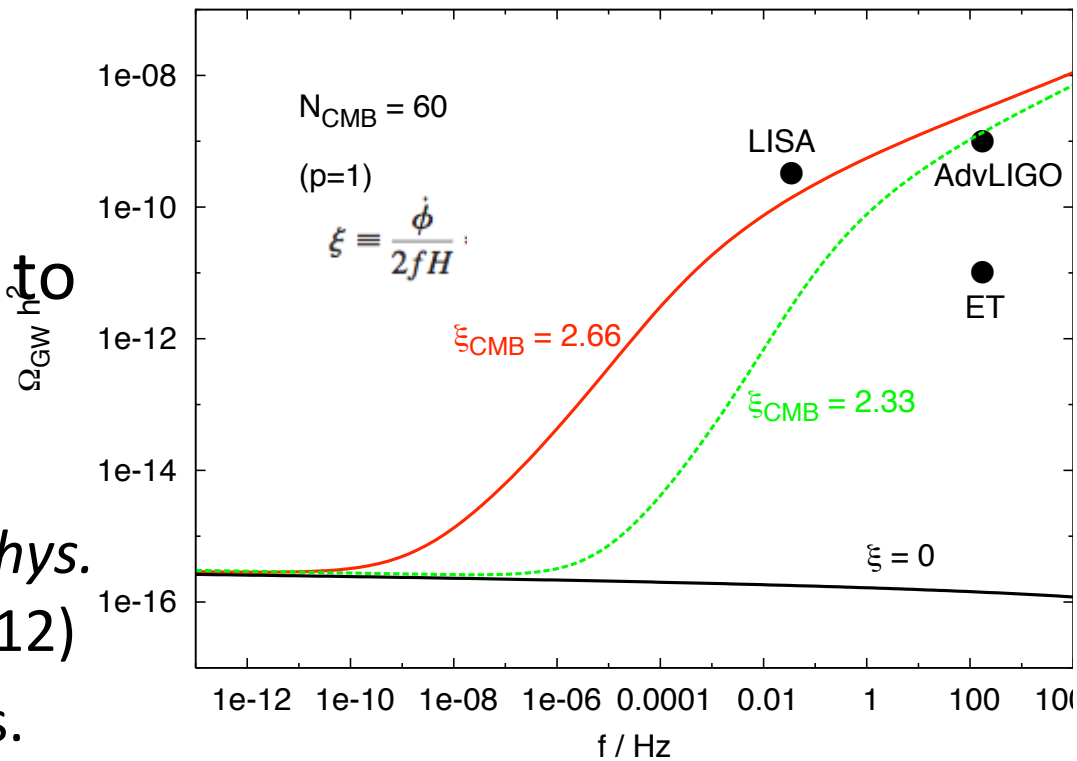

Results from initial LIGO

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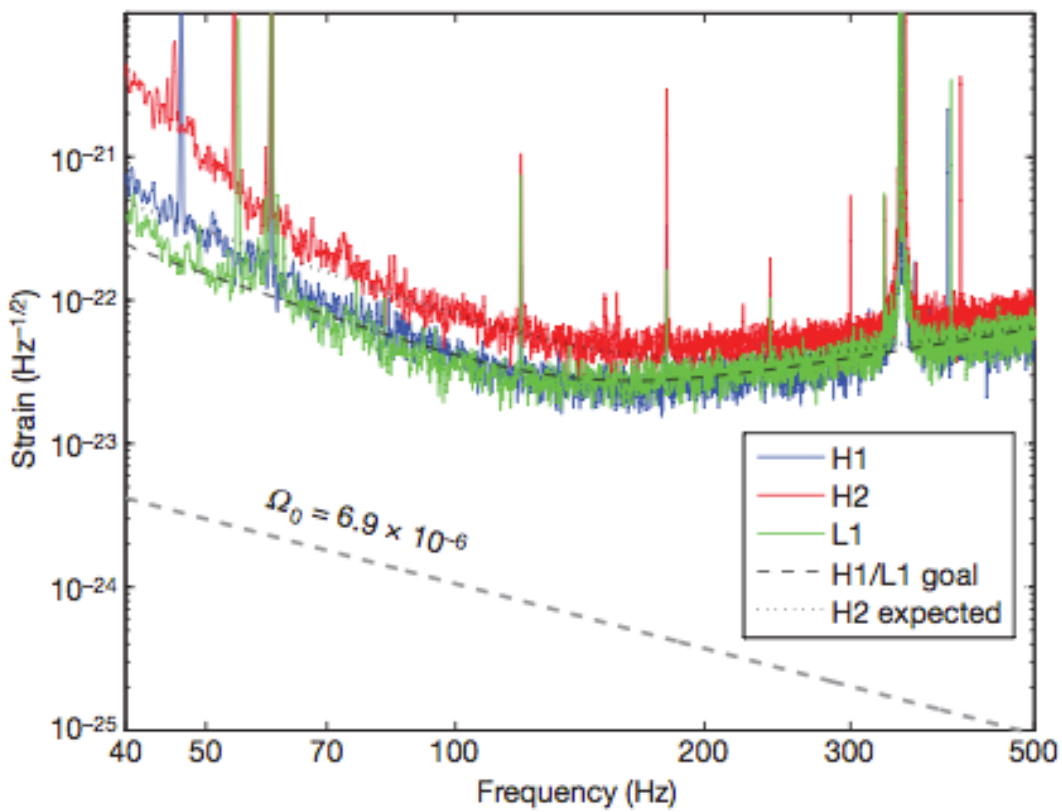

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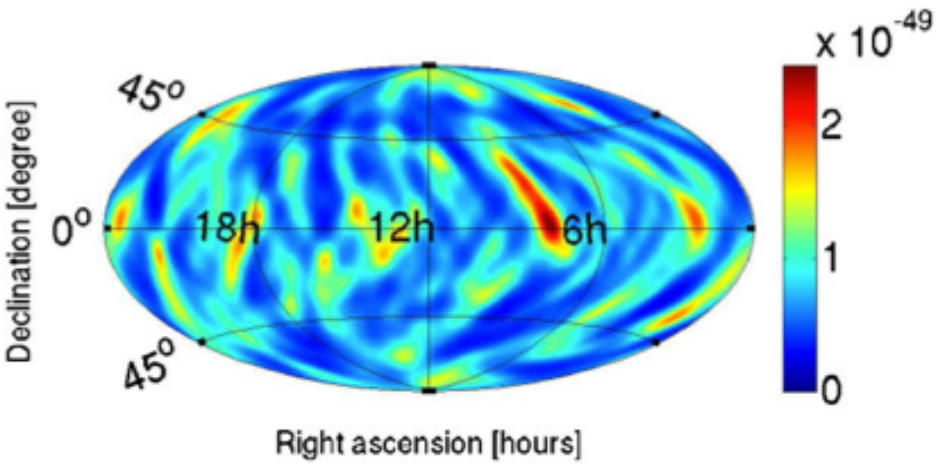
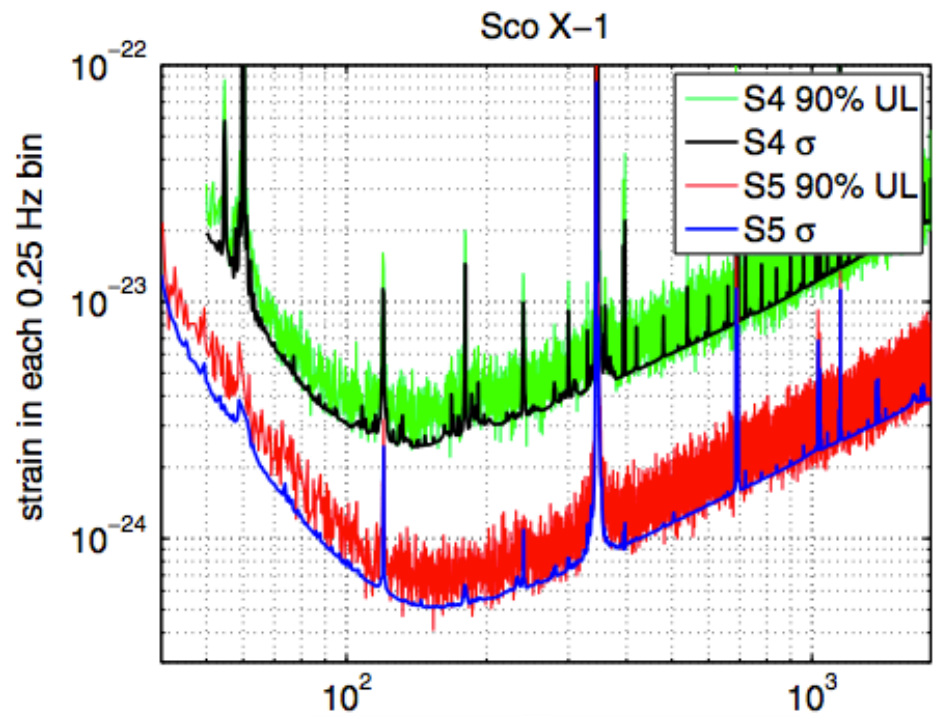
Directional searches



GW sky maps

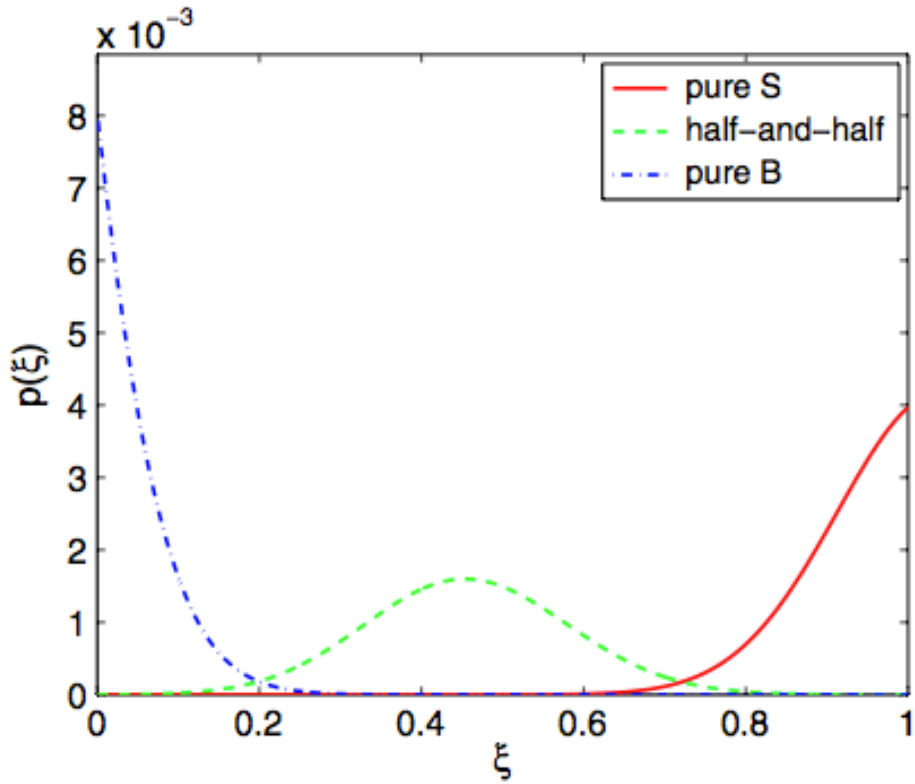


directed searches

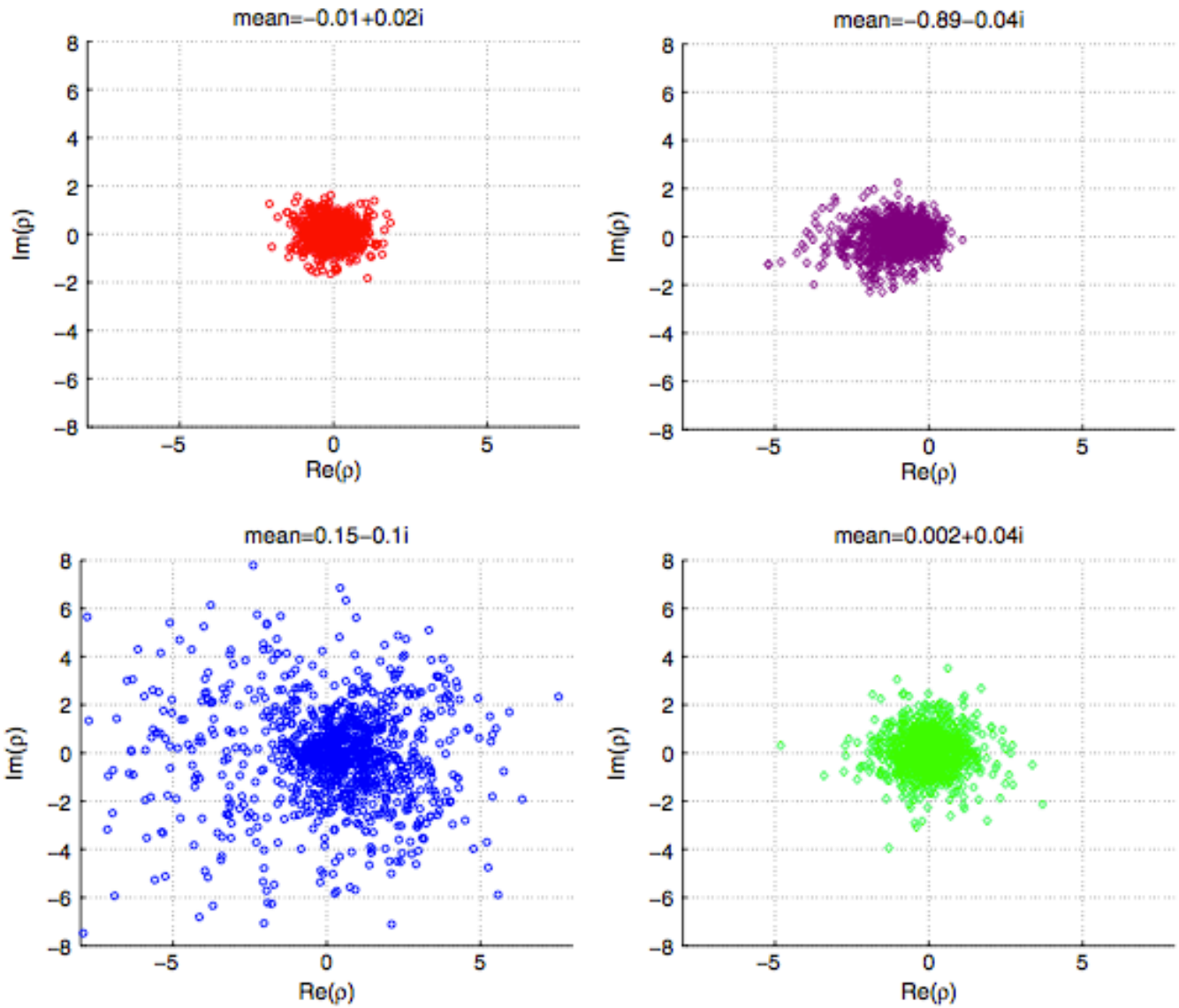
J. Abadie *et al.*, PRL 107, 271102 (2011)

Non-Gaussianity

- Recent work* suggests it may be possible to exploit non-Gaussianity of astro GW background to
  - Measure coalescence rate
  - Improve detection
- Ongoing work to test new ideas and validate analysis tools with mock datasets.
  - Building on T. Regimbau et al., Phys. Rev. D 86, 122001 (2012)



Coalescence rate from duty cycle: a toy model.

* E. Thrane, PRD **87**, 043009 (2013)

Signatures of non-Gaussianity