Astrophysical Stochastic Gravitational Waves

Jonah Kanner – PHYS 798G – March 27, 2007

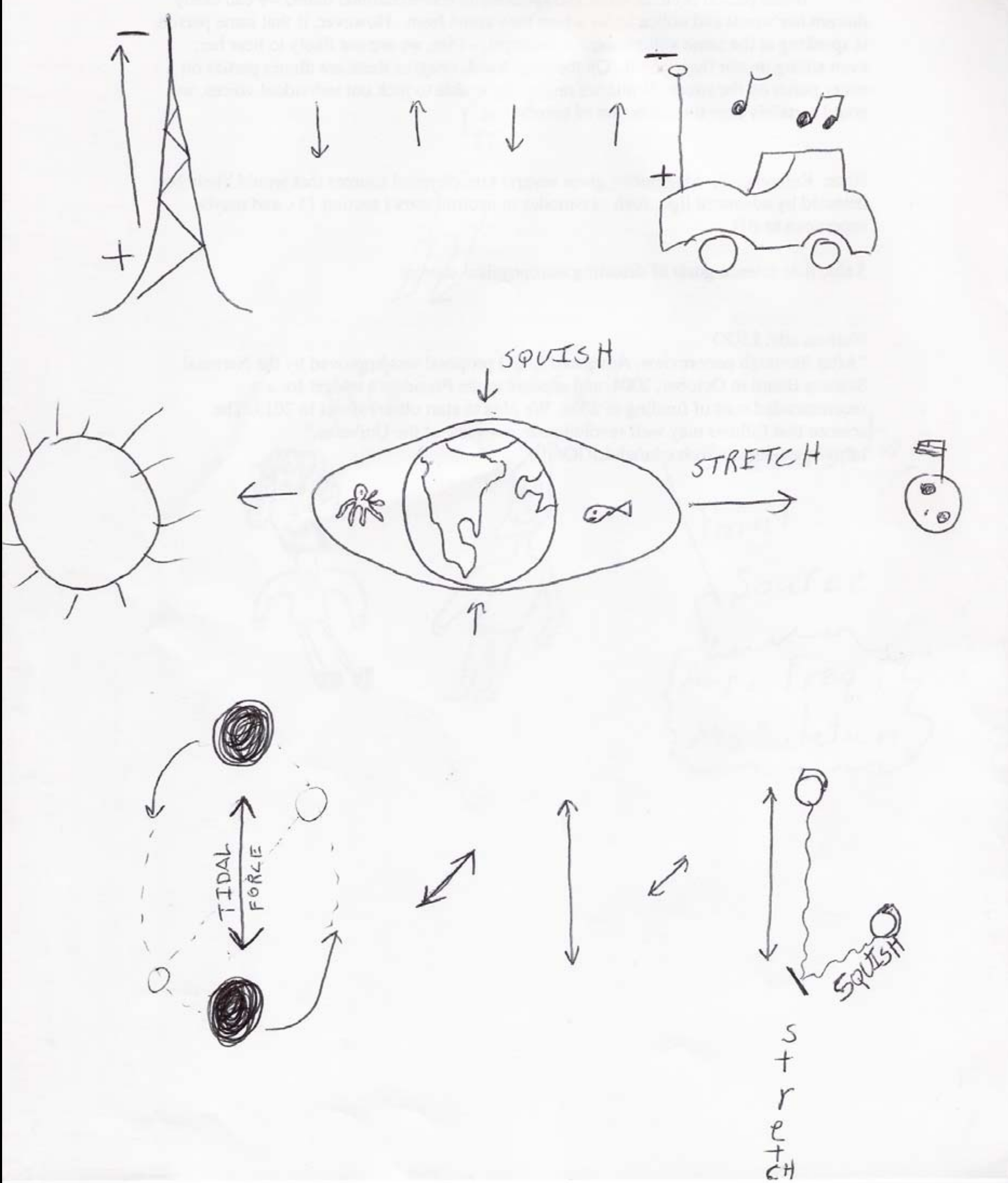
Introduction

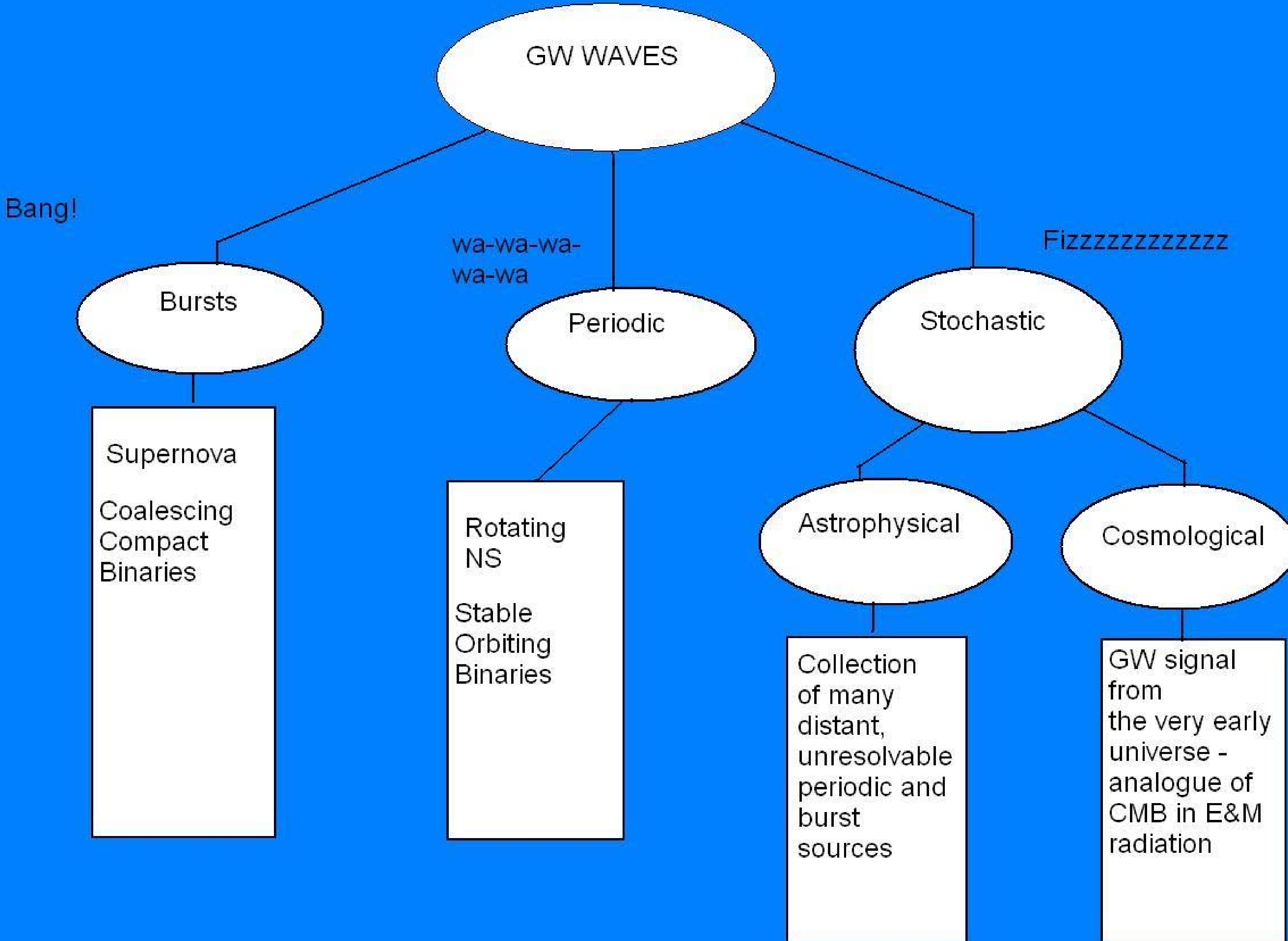
- Gravitational Waves come from space
- Require acceleration of dense mass (Think black holes and neutron stars!)
- Will be detected with resonant bars and interferometers (both exist and are improving!)

E-M Waves come from moving charges, flipping field lines back and forth.

Gravitational quadra-pole fields lead to tidal forces. The “tidal forces” describe the field – ocean not required!

GWs come from moving masses, flipping a tidal stretch back and forth across 2 orientations.




GW WAVES
Bang!
Bursts
Supernova
Coalescing Compact Binaries
wa-wa-wa-wa-wa
Periodic
Rotating NS
Stable Orbiting Binaries
Fizzzzzzzzzzzz
Stochastic
Astrophysical
Collection of many distant, unresolvable periodic and burst sources
Cosmological
GW signal from the very early universe - analogue of CMB in E&M radiation

Introduction

- Current detectors measure mainly ~50-3000 Hz

  (In band of human hearing!)

Merger (burst)

http://www.ligo.caltech.edu/~mours/bh-no-noise.au

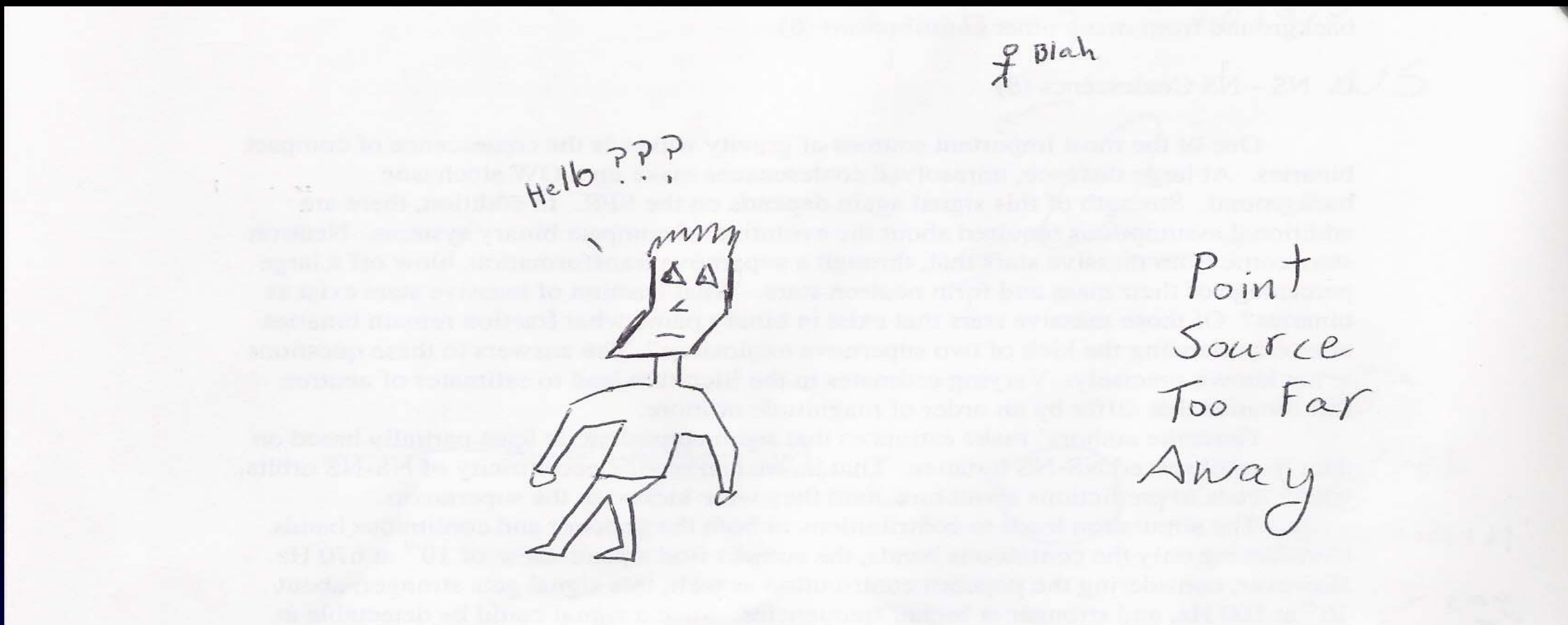
Inspiral
(~periodic)

SN
Stochastic
(popcorn)

http://www.physics.uwa.edu.au/~coward/SIMULATION.htm

http://gmunu.mit.edu/sounds.html

Hi!
Hi!
Conversation
Point
Source
Amp, Freq,
Modulation



Blah
Hello???
Point Source Too Far Away


QUIET!!!!
Blah
Blah
Blah
Blah
Blah
Blah
Blah
Blah
Blah
Blah
Blah
Blah
Blah
Blah
Blah
Blah

What is the Astrophysical Background???

- What: Many points sources overlapping in time
- Quick Math: Imagine a spherical shell
  - Number of sources/shell N ~ r^2
  - Amplitude per source A ~ 1/r
  - Net Amp ~ Random Walk ~ A*sqrt(N) ~ CONSTANT!

Result: A background fuzz from redshift z~1-5

Characterization

- Omega!!!!!!

$\Omega(f)$ is roughly the normalized energy density in a given frequency band of the stochastic background

$\int \Omega(f)\, d(\ln(f)) = \rho_{GW}/\rho_c$

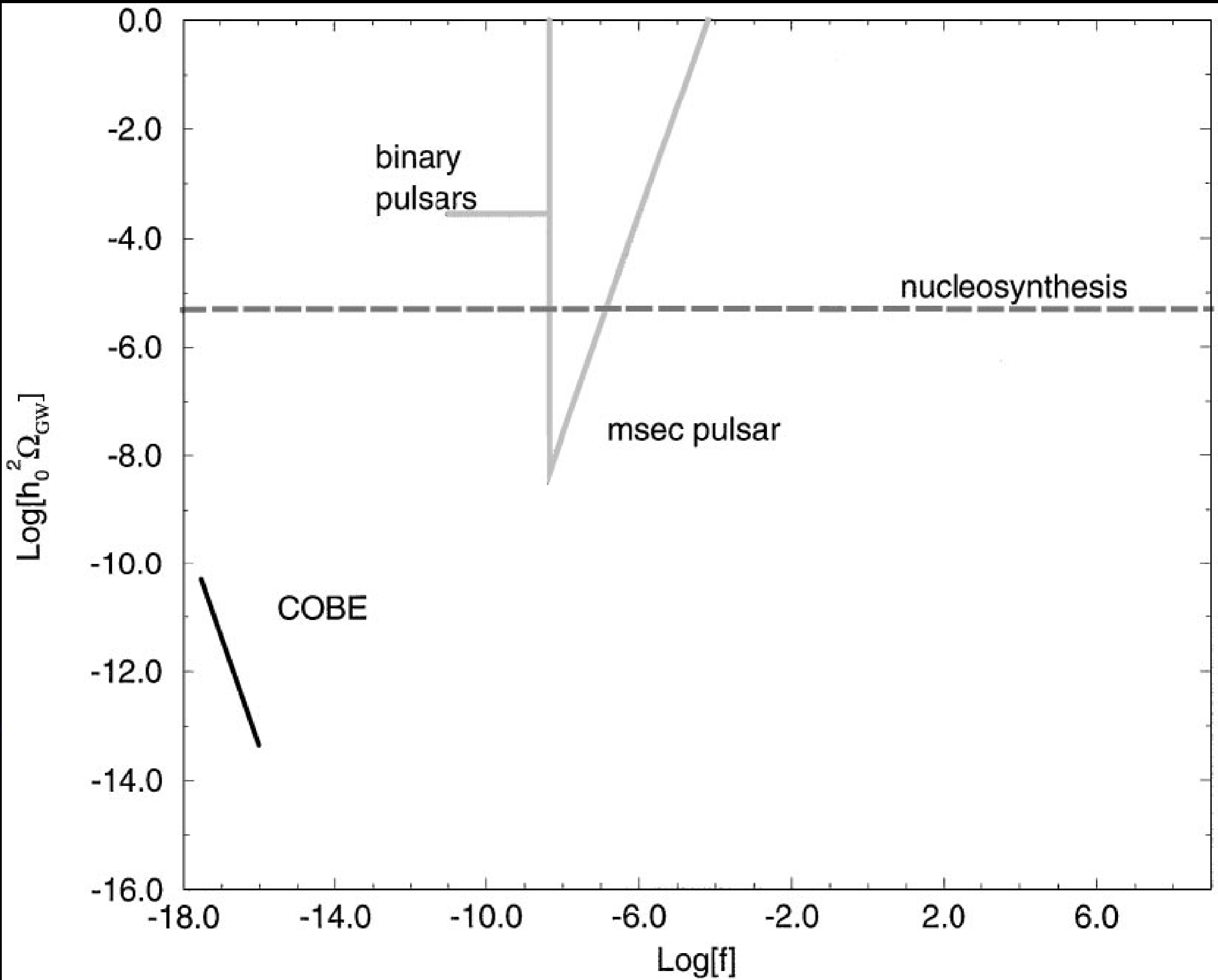
In the same sense that a single temperature (2.7 K) completely describes the CMB, omega completely describes the GW background if it's stationary, Gaussian, and isotropic

Convention: Bound Ω_0

Measurement - Indirect

The nucleosynthesis bound applies only to Cosmological signals

For high freq, it's a wide open field!



Maggiore, M. 2000, Physics Reports. 331, 283

Measurement – IFO's & Bars

- LIGO, TAMA, GEO,VIRGO
- Bar Detectors
- Advanced Detectors (LIGO, VIRGO) ~ 2013

Current bound on Ω of about 10^-5 at 50-150 Hz

Bounds around 10^-9 from "adv" IFOs (50-150Hz)

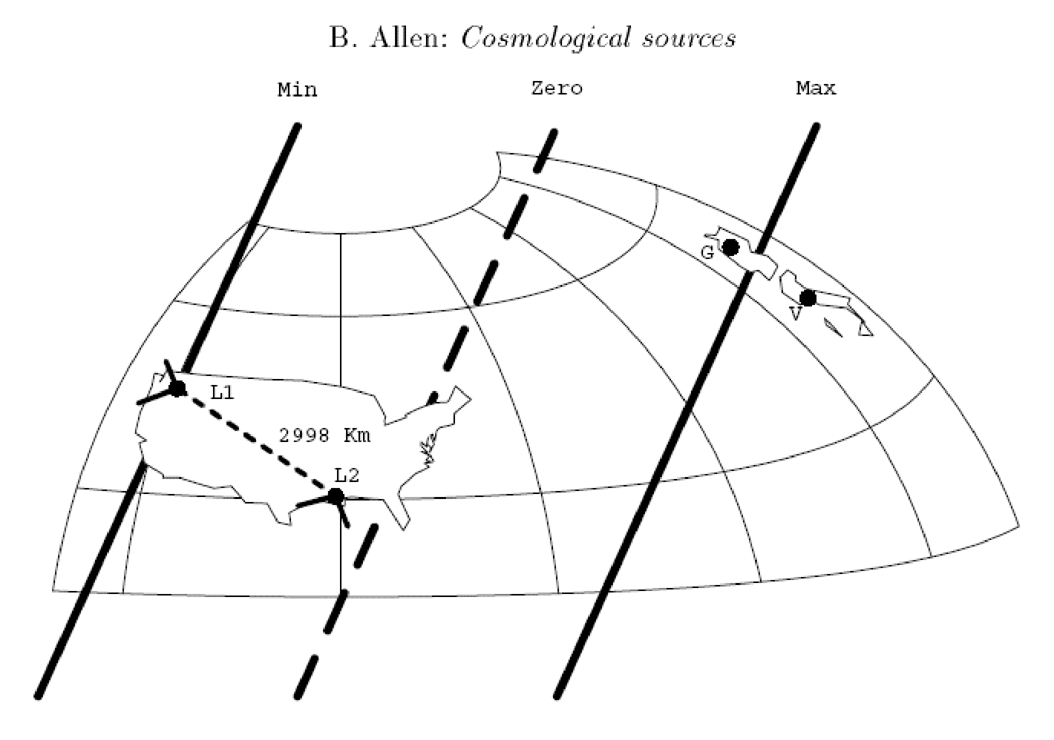
Bars + IFOs for higher frequency bounds

Measurement

- Cross Correlation

  Idealization (IFOs at same place): $\int s1(t)\, s2(t)\, dt$

Limitation: IFOs are usually not in the same place!! Wavelengths much shorter than 3000 km (100 Hz) will get “washed out” of cross correlation for L1-H1 pair



Allen, B. 1996, gr-qc/9604033

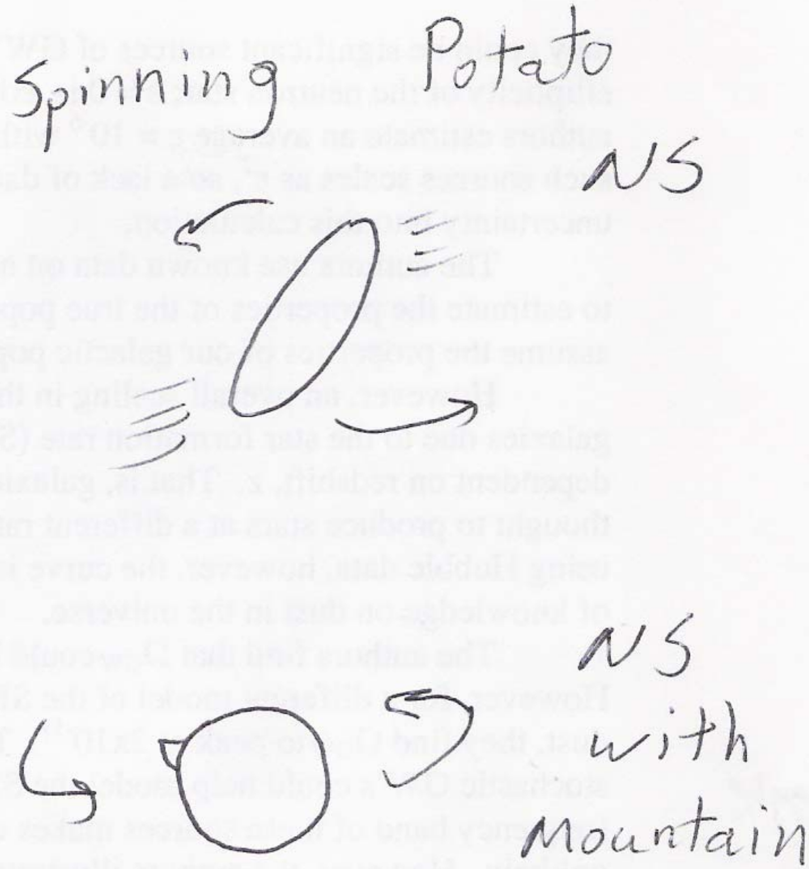
Sources

Estimation

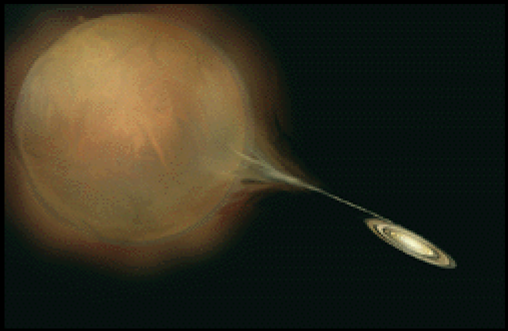
- Star Formation Rate (SFR)
- Galactic Population Properties
  (Magnetic fields, freq, masses, etc…)
- GW strength per source

Eccentric Neutron Stars

- Eccentricity may be any asymmetry with respect to axis of rotation (potato or mt.)
- Use pulsar data to make estimates on the properties of the spinning neutron star population (also LMXB's and HMXB's)
- ε is difficult to estimate – existing upper bounds, but hard to get a good value


Spinning Potato
NS
NS
with
Mountain

Eccentric Neutron Stars



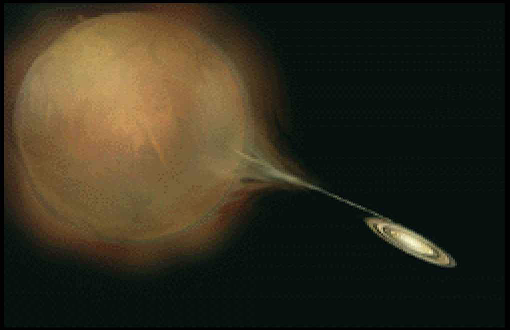
T. Regimbau and J. A. de Freitas Pacheco estimate Ω between 10^-9 and 10^-11

-- Assume ε = 10^-6 (?)

-- Wide range of Ω_0 comes from different models of SFR (corresponding to different models of cosmic dust)

-- Freq ~1-1.5 kHz (from pulsar freq.)

Eccentric Neutron Stars



Not promising for IFO alone (high freq!)

--Bars + IFO might do it

R-modes might do better

Tough estimate! Measurement probes SFR

Supernovas (ka-pow!)

David M. Coward,P Ronald R. Burman and David G. Blair consider NS forming SN

SN still not well understood – authors consider a mix of three different models – GW production depends on asymmetry of simulation

Supernovas (ka-pow!)

- Popcorn noise
- Get Ω about 10^-12 peaked at 200-300 Hz
- With BH forming SN, could be closer to 10^-10

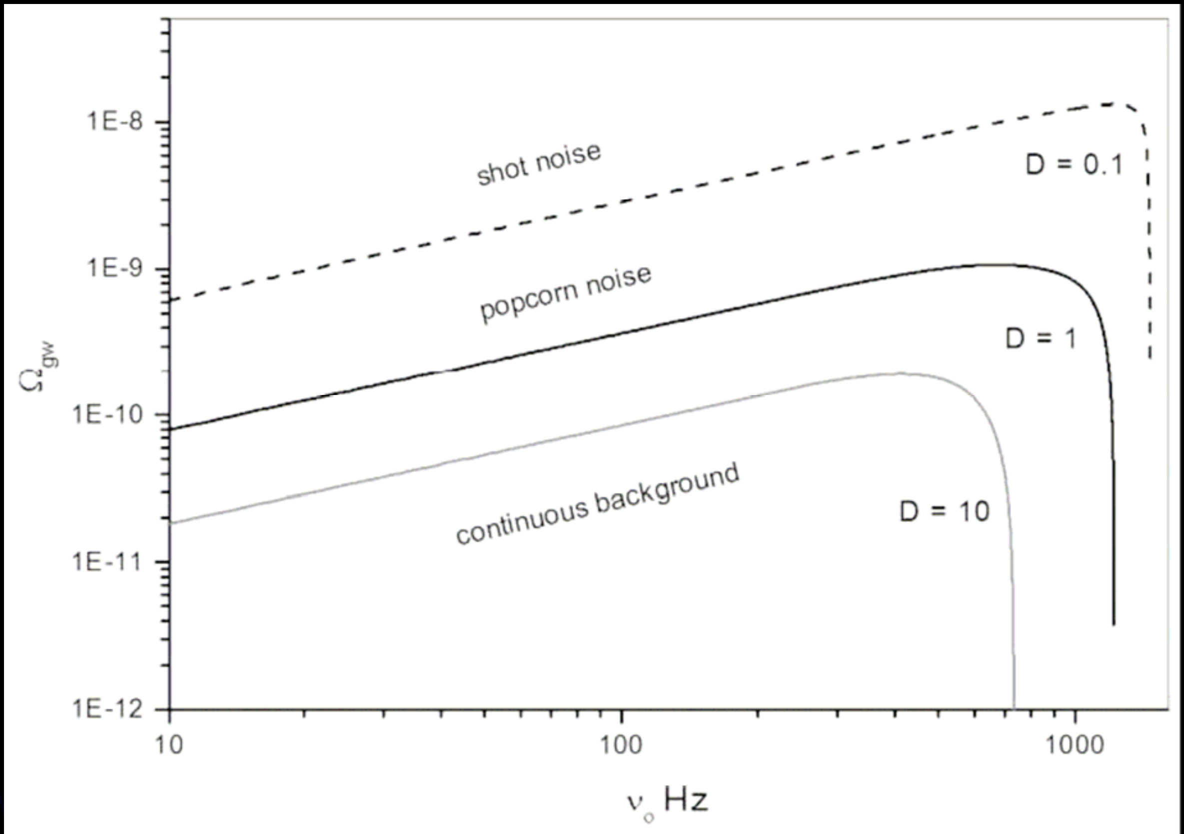
Neutron Star Coalescence

- Hard things to estimate: What fraction of massive stars exist as binaries??
- Of those, what fraction are binaries after 2 SN's ??
- Can use eccentricity of pulsar orbits to estimate "kick" from SN

Neutron Star Coalescence

T. Regimbau and J. A. de Freitas Pacheco

Should be visible by Advanced IFOs

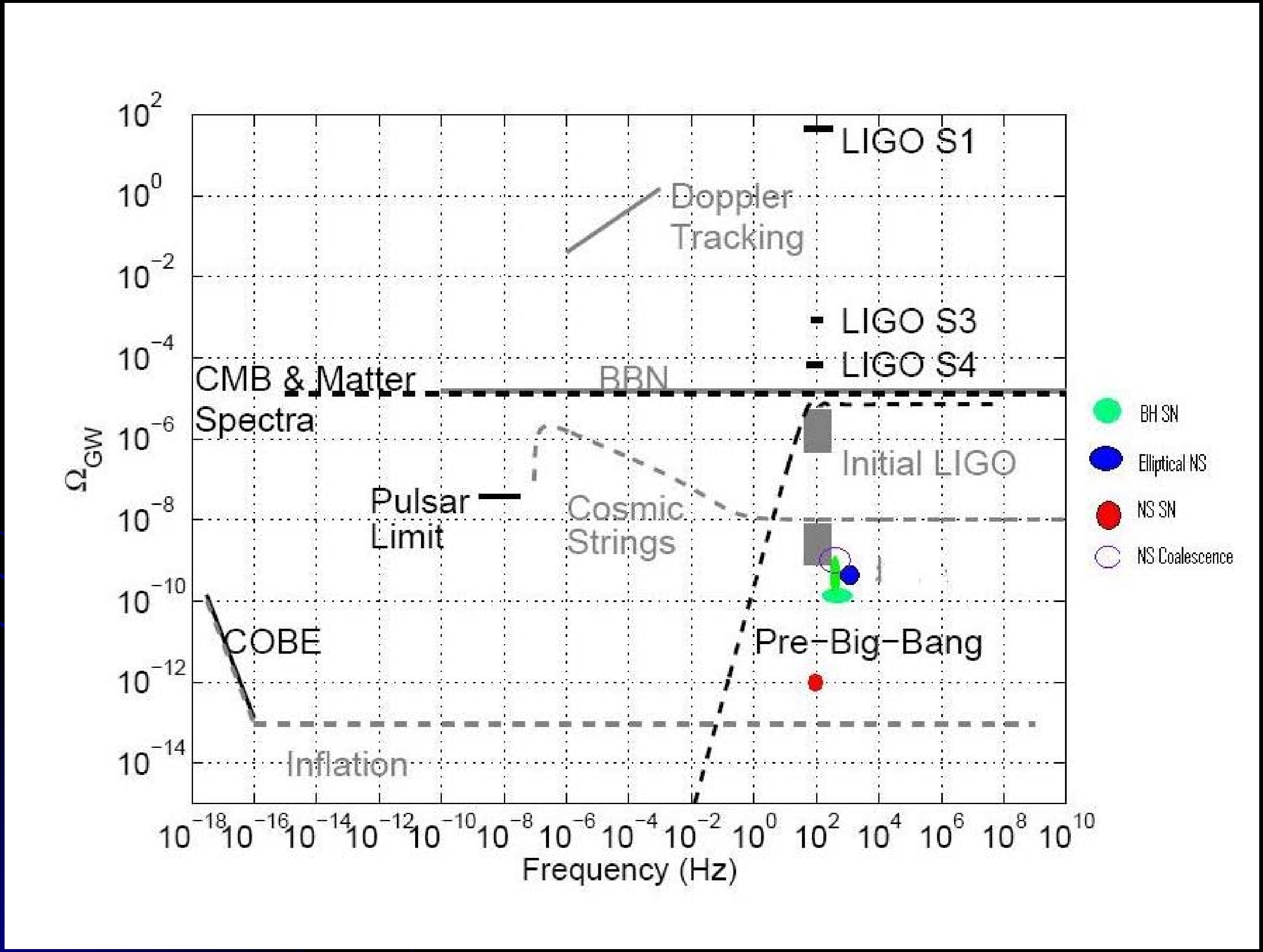


Regimbau, T. & de Freitas Pacheco, J. A. 2006, The Astrophysical Journal. 642, 455

Science

- Probe the SFR (clear up the dust issue)
- Snapshot of universe, z ~ 1- 5
- Rates of supernovas, mass and angular momentum distributions of compact objects, and ratios between formation of black holes and neutron stars, etc.
- Astrophysical Stochastic signal may have to be understood and removed to see Cosmological signal

A Rough Sketch



MODIFIED FROM: Abbott, B., et al. (LSC) 2006, astro-ph/0608606

References

- Supernova image
  http://hubblesite.org/newscenter/archive/releases/star/supernova/2007/10/image/a/
- Binary NS image
  http://chandra.harvard.edu/photo/2005/grb050709/animations.html
- Ns image
  http://www.astro.cf.ac.uk/groups/relativity/research/part13.html

Abbott, B., et al. (LSC) 2006, astro-ph/0608606
Allen, B. 1996, gr-qc/9604033
Cooray, A. 2004, Mon. Not. R. Astron. Soc. 354, 25
Coward, D.M., Burman, R.R. and Blair, D.G. 2002, Mon. Not. R. Astron. Soc. 329, 411
Maggiore, M. 2000, Physics Reports. 331, 283
Regimbau, T. & de Freitas Pacheco, J.A. 2001, Astron. and Astrophys. 376, 381
Regimbau, T. & de Freitas Pacheco, J. A. 2006, The Astrophysical Journal. 642, 455
http://www.ligo.caltech.edu/advLIGO, 2005