Review of stochastic sources of gravitational radiation

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Outline

- Introduction: general features
- Cosmological (primordial) sources
- Astrophysical sources (galactic and extragalactic)

Possible target of GW experiments

Stochastic background of GW

Random process, described only in terms of its statistical properties (isotropic, unpolarised, stationary, gaussian)

$$\Omega_{\rm gw} = \frac{1}{\rho_c}\frac{d\rho_{\rm gw}}{d\ln f}\,,\rho_c = \frac{3c^2H_0^2}{8\pi G}$$

$$\Omega_{\rm gw} = \frac{4\pi^2}{3H_0^2}f^3 S_h(f)$$

- **Primordial:**

Parametric amplification of vacuum fluctuations during inflation, phase transitions (QCD,EW), non-equilibrium processes (reheating..), topological defects

- **Astrophysical:**

Large populations of binary systems of compact objects (wd,ns,bh), hot, young rapidly spinning NS (r-modes)…

Characteristic frequencies of GW stochastic backgrounds (primordial)

For relic gravitational waves, two features determine the tipical frequency: the dynamics of production mechanism (model dependent) and the kinematics (redshift from the production time)

For a graviton produced at time t_* with frequency f_* during RD or MD epoch

$$f = f_* \frac{a(t_*)}{a(t_0)}, \quad g a^3 T^3 = \mathrm{const}$$

$$\frac{1}{f_*} = \lambda_* = \epsilon H_*^{-1}$$

$$f \sim 1.6 \times 10^{-7} \frac{1}{\epsilon} \left(\frac{T_*}{1\mathrm{GeV}} \right) \left(\frac{g_*}{100} \right)^{1/6} \mathrm{Hz}$$

(Kamionkowski et al ‘94, Maggiore ‘00)

Phenomenological bounds

$$\int h_0^2 \Omega_{GW}(f)\, d\log f \le 5.6\times 10^{-6}(N_\nu - 3)$$

BBN bound (Copi Schramm, Turner 97)

$$h_0^2 \Omega_{GW}(f) \le 7\times 10^{-11}\left(\frac{H_0}{f}\right)^2$$

$$H_0 \le f \le 10^{-16}\,\mathrm{Hz}$$

COBE bound (Koranda, Turner 94)

$$h_0^2 \Omega_{GW}(f) \le 4.8\times 10^{-9}\left(\frac{f}{f_P}\right)^2$$

$$f \ge f_P = 4.4\times 10^{-9}\,\mathrm{Hz}$$

Msec pulsar bound (Thorsett, Dewey 96)

Production mechanisms and characteristic amplitudes of GW stochastic backgrounds (primordial)

Amplification of vacuum fluctuations
(Grishchuk '75; Starobinski '78…)

$$f \in [10^{-18}\,\mathrm{Hz}, 1\,\mathrm{GHz}]$$

Slow-roll inflation: almost flat spectrum

(see e.g. Turner '97)

$$h_0^2 \Omega_{GW}^{max} \le 10^{-15},\; f \in [10^{-4}, 10^{3}]\,\mathrm{Hz}$$

Pre-big-bang inflation
(see e.g. Buonanno, Maggiore, U 97)

$$h_0^2 \Omega_{GW}^{max} \le 10^{-7},\; f \in [10^{-4}, 10^{3}]\,\mathrm{Hz}$$

EW first order phase transition ($T_* \sim 100$GeV)

$$f_{peak} \sim 10^{-4} - 10^{-3}\,\mathrm{Hz}$$

In SM there is no first-order phase transition for $m_H > M_W$

In MSSM there are possibilities (depending on m_H) but
(Kosowsky ,Turner 94; Kosowsky, Turner , Kamionkowski 94)

$$h_0^2 \Omega_{GW} \le 10^{-16}$$

In NMSSM
(Apreda, Maggiore, Nicolis, Riotto, 01, Apreda 03)

$$h_0^2 \Omega_{GW} \le 10^{-15} - 10^{-10},\; f_{peak} \sim 10^{-2}\,\mathrm{Hz}$$

GW from cosmic turbolence
Kosowsky et al, Apreda et al 01, dolgov et al '02

$$h_0^2 \Omega_{GW} \sim 10^{-10},\; f \sim 10^{-3}\,\mathrm{Hz}$$

Gw from bubble collision in false vacuum inflation
If phase transition occurs before the end of inflation
(Baccigalupi et al, 97)

$$f_{GW} \sim 10 - 10^{3}\,\mathrm{Hz}$$

Detection of primordial backgrounds (I)

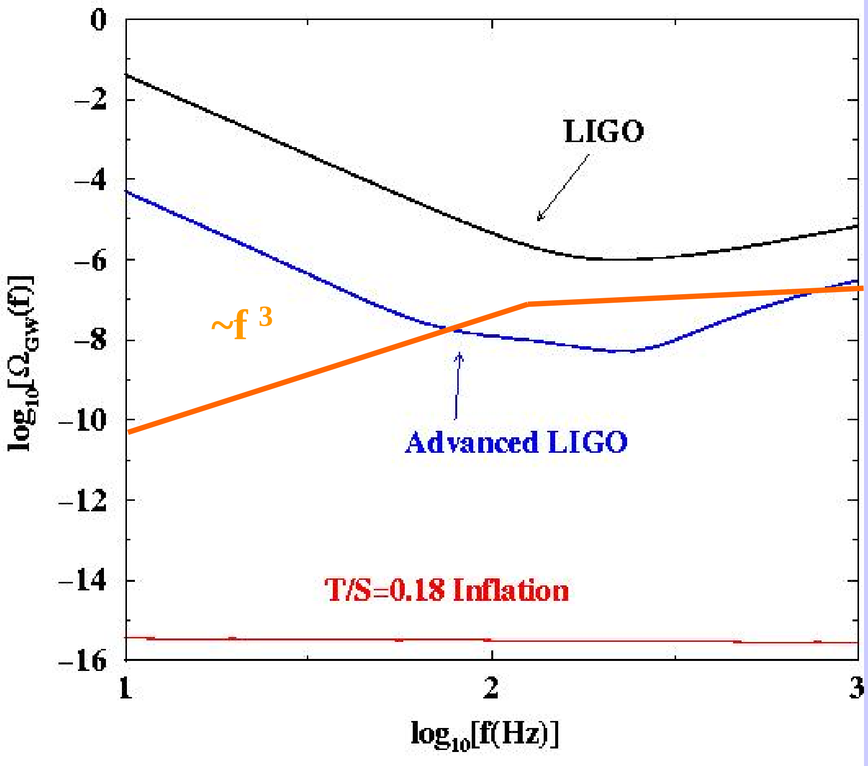
Earth-based interferometers

Design sensitivity of current Interferometers $h_0^2 \Omega_{\rm gw}^{\rm min} \sim 5 \times 10^{-6}$ (See e.g Allen, Romano '99)

Second generation detectors [Advanced LIGO] $h_0^2 \Omega_{\rm gw}^{\rm min} \sim 10^{-8}$

3rd generation European Gravitational Observatory $h_0^2 \Omega_{\rm gw}^{\rm min} \sim 10^{-10}$

- **String-inspired inflationary models (e.g. pre-big-bang) could be tested by second generation detectors**
  (Allen, Brustein 97; U, Vecchio 99; Vuk, Buonanno '05)
  Warnings: the models do not provide reliable description of transition to post-big-bang era; the observability of GW spectrum depends on the detail of the transition

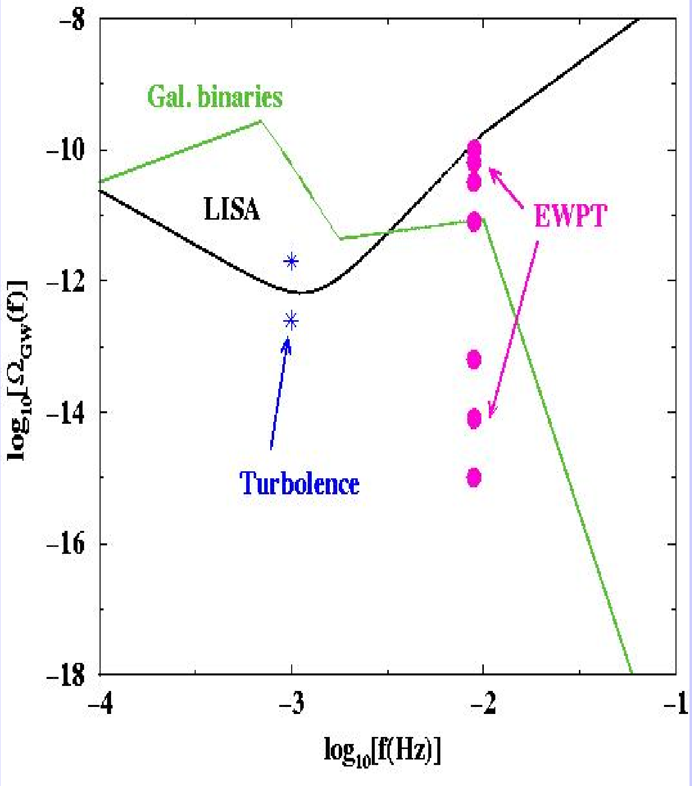


Detection of primordial backgrounds(II)

Space-based interferometers

Astrophysical backgrounds

Incoherent superposition
of GW emitted by short-period, solar mass binary systems (WD,NS..)
Galactic and extra-galactic contribution
(Bender et al, 90,97; Postnov et al, Schneider et al 00)



- **The signal produced by the galactic background dominates the instrumental LISA noise ~ mHz**

Stochastic backgrounds from Astrophysical Sources

Cumulative GW signal due to the uncorrelated emission of populations of sources

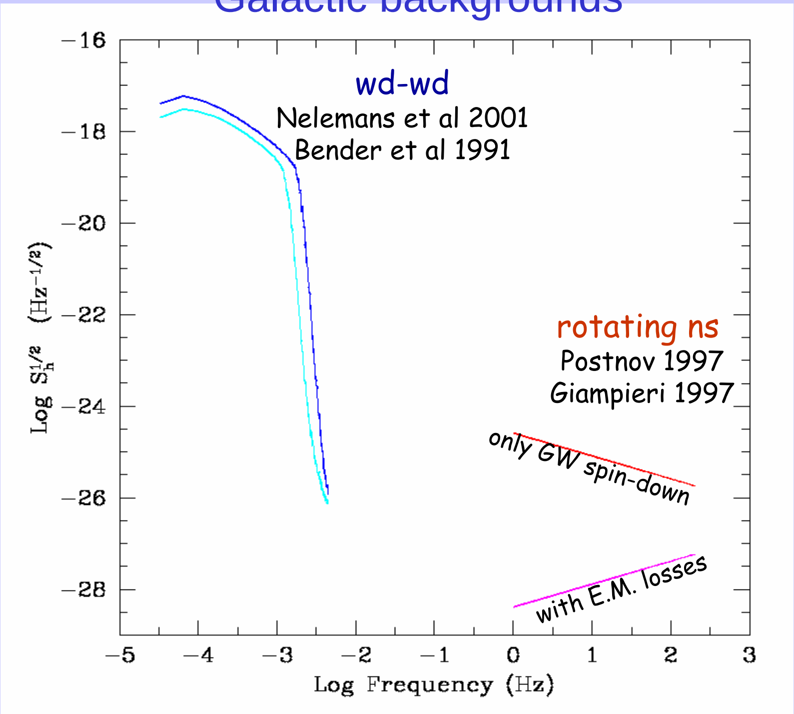
The signal produced is stochastic when

$$N_\Delta = \frac{dN}{df}\Delta_b f > 1, (\Delta_b f = T_{obs}^{-1})$$

$$N_\Delta \sim 80\left(\frac{10^{-3}\,\mathrm{Hz}}{f}\right)^{11/3}\left(\frac{0.5M_\oplus}{\mu}\right)^{5/3}\left(\frac{\Gamma_{coal}}{0.003\,yr^{-1}}\right)\left(\frac{1\,yr}{T_{obs}}\right)^{11/3}$$

(Ex. Galactic wd-wd)

Galactic backgrounds



(Courtesy of R.Schneider)

Amplitude modulation of the signal due to the anisotropic distribution of the emitting sources

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Can be used to identify sucb signals

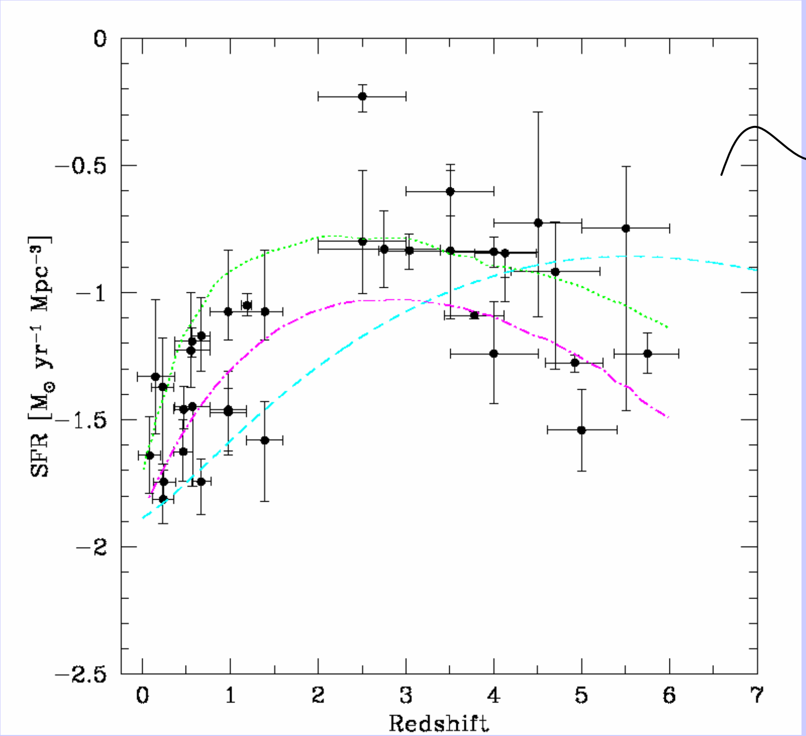
Giampieri, Polnarev' 97; Giazzotto et al '97; U and Vecchio, '01

Extragalactic backgrounds
generated by all GW sources formed in the universe since the onset of star formation

- fundamental backgrounds limiting the sensitivity of GW instruments
- astrophysical foregrounds for primordial GW from the early universe
- provides combined constraints on the star formation history and GW source emission properties

Realistic estimates require knowledge of the
- source formation rate
- individual emission properties

"Recovered" Star formation history out to z~6 (~1 Gyr)
(Nagamine et al '04)



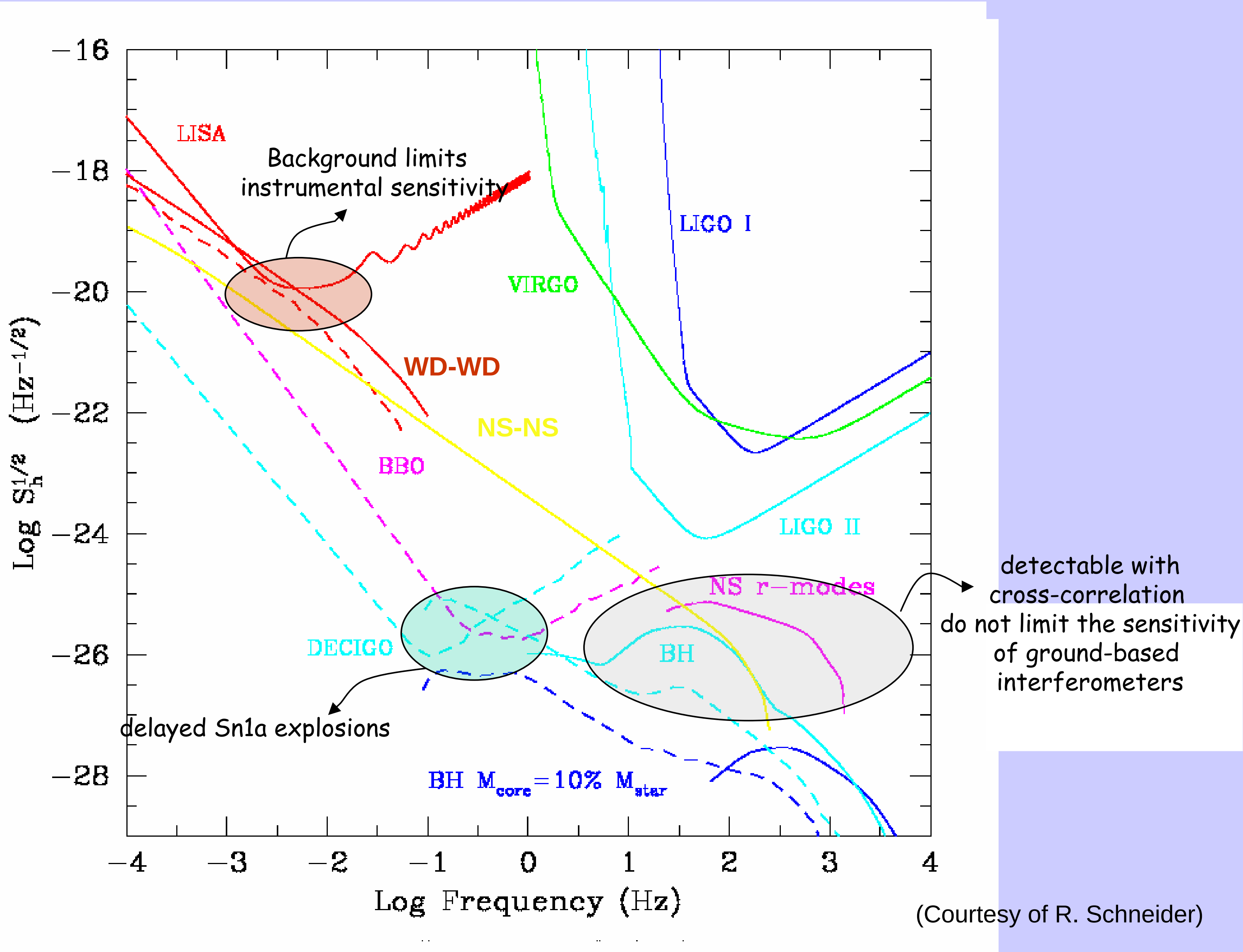
Additional information required:

-stellar Initial Mass Function (black holes, neutron stars)

-binary population synthesis code
(initial masses, orbital separations, eccentricities)

Extragalactic backgrounds: present status

Schneider, Matarrese, Ferrari '99, '01; Farmer, Phinney '03; Buonanno et al. '05



(Courtesy of R. Schneider)