Excitation of stellar oscillations by gravitational waves

Daniel M. Siegel and Markus Roth
Kiepenheuer Institute for Solar Physics, Freiburg, Germany

Kiepenheuer-Institut für Sonnenphysik

Introduction

The universe is expected to be penetrated by a stochastic background of gravitational radiation (SBGW) of astrophysical and cosmological origin, similar to the cosmic microwave background (CMB) [1-3]. Such a background should contain unique signatures from the very early universe and would thus yield unprecedented information about its evolution, which is inaccessible to astrophysical observations based on electromagnetic waves. In the work underlying this poster [1,4,5], we demonstrate that stellar oscillations are excited by an SBGW and that stars, as observed by *Kepler*, can be employed as giant hydrodynamical detectors for such a background. Measuring or constraining the amplitude of such a background has important consequences for early-universe cosmology, high-energy particle physics, and even string theory.

Excitation model

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu} \qquad (1)$$

$$\Downarrow$$

$$\rho \left(\frac{\partial^2}{\partial t^2} - \mathcal{L} \right) \mathbf{v}_{\rm osc} + \mathcal{D}(\mathbf{v}_{\rm osc}) = \frac{\partial}{\partial t} (\mathbf{f}_{\rm Rey} + \mathbf{f}_{\rm Entr} + \mathbf{f}_{\rm GW}) \qquad (2)$$

- Hydrodynamic formalism derived from the field equations (1) of general relativity, which yields the mean-square amplitudes and rms surface velocities of stellar normal modes excited by arbitrary gravitational waves (GWs)
- Generalized and unified theoretical description of the mode excitation processes due to turbulent convection [6,7] and GWs, combined in a single forced wave equation (2) with Reynolds, Entropy and GW source terms
- The mean-square amplitude of a particular eigenmode N in the case of excitation by an SBGW is given by

$$\left\langle |A_N|^2 \right\rangle = \frac{\pi^2}{25} \frac{R^8 \chi_N^2}{\eta_N \omega_N I^2} H_0^2 \Omega_{\rm GW}(\omega_N), \qquad (3)$$

  where R is the radius of the star, χ_N a resonance factor, η_N the damping rate, ω_N the oscillation frequency, I the mode inertia, H_0 the present Hubble expansion rate, and $\Omega_{\rm GW}$ denotes the normalized, dimensionless spectral energy density of the SBGW

Results for the Sun

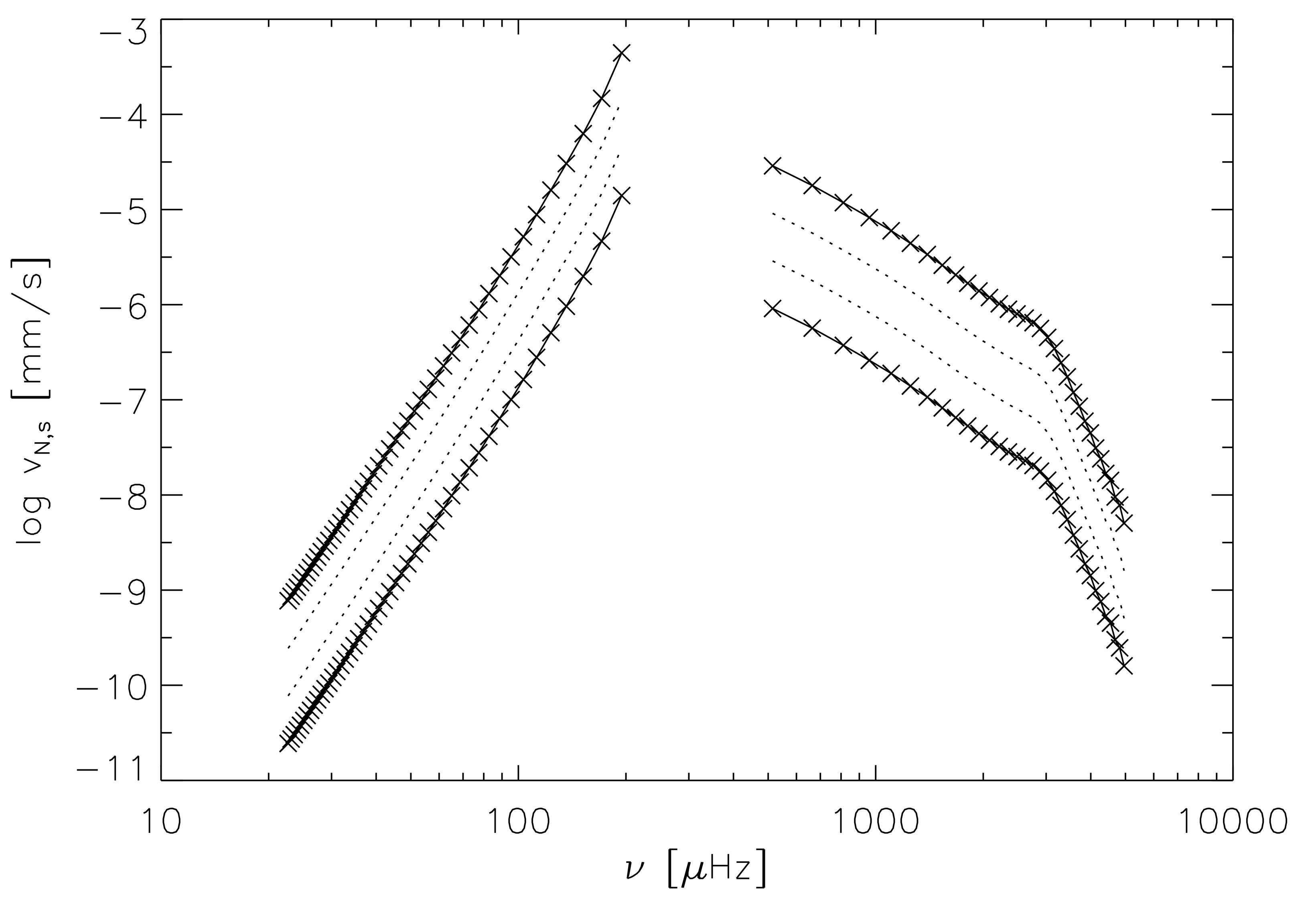

Figure: Numerical results for rms surface velocities of $l = 2$ solar g and p modes, assuming a constant spectral energy density of $\Omega_{\rm GW} = 1 \times 10^{-5}$ (top curve) and $\Omega_{\rm GW} = 1 \times 10^{-8}$ (bottom curve).

- Low-order solar g modes are generally excited more strongly by an SBGW than p modes (by orders of magnitude)
- Maximal solar g-mode rms surface velocities of $10^{-5} - 10^{-3}$ mm s^{-1} (when excited by an SBGW) lie close to or within the amplitude range of $10^{-3} - 1$ mm s^{-1} expected from stochastic excitation by turbulent convection, which is currently considered to be responsible for g-mode excitation in solar-like stars [8,9]

Constraining a stochastic background of GWs

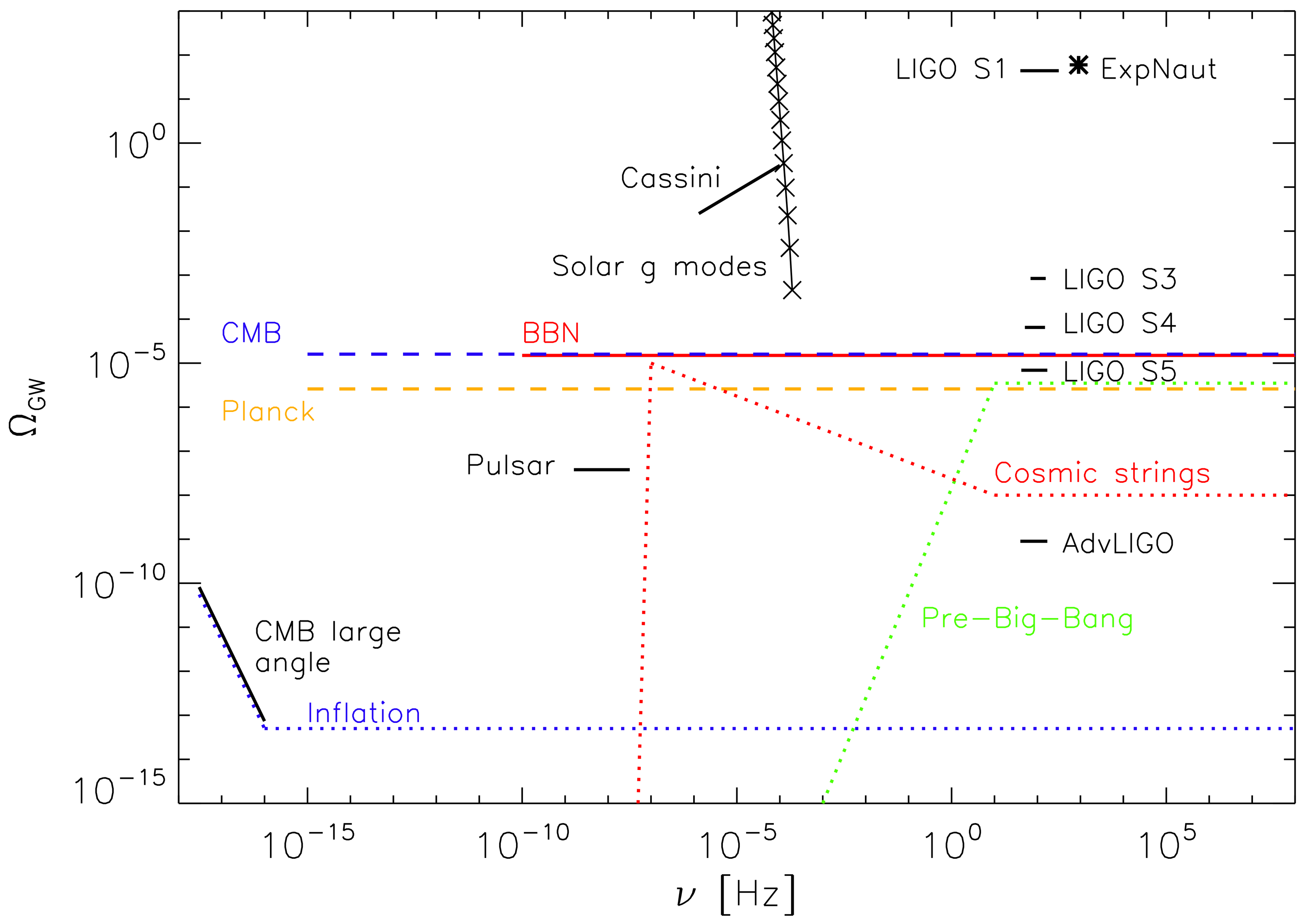

Figure: Potential upper limit from solar g modes on the spectral energy density $\Omega_{\rm GW}$ of an SBGW, based on present estimates for solar g-mode amplitudes [8-10]. The following observational bounds are also shown: the upper limit from Doppler tracking of the *Cassini* spacecraft [11], the bounds from the S1-S5 *LIGO* science runs [12-15], the most stringent bound from cryogenic resonant bar detectors (ExpNaut; [16]), the Pulsar bound [17], the (indirect bounds) from CMB measurements and big bang nucleosynthesis [18,2,19], and the expected future bounds from *Planck* [18] and *advanced LIGO* [20]. Furthermore, typical models for a stochastic background from some of the most anticipated sources are indicated (dotted lines; [1,15]); the amplitudes and spectral shapes may vary significantly with model parameters.

Conclusion

- As only $l = 2$ modes can be excited by GWs, experimental data for other harmonic degrees can be employed to test, calibrate and disentangle the contributions due to other excitation mechanisms
- Regarding an upper limit on an SBGW, asteroseismic observations of g modes might have the potential to compete with Earth-based interferometric detectors and the cosmological experiments
- Asteroseismic observations would yield a direct upper bound in an intermediate frequency range where to date significant direct upper bounds do not exist
- This method opens up an exciting possibility for asteroseismology to probe fundamental physics

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Contact: dsiegel@kis.uni-freiburg.de, mroth@kis.uni-freiburg.de