

Wideband “bar” detectors and kHz gw sources: AURIGA on the Dec04 X-rays giant flare and beyond with DUAL

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Abstract. We discuss the interest of acoustic gw detectors for sources in the kHz range. As an example we summarize the recent upper limits in gw emission, posed by AURIGA on the Dec 2004 X-rays giant flare and see how they would improve with upgraded AURIGA in the near future. In the 2013 timeframe, a fully wideband DUAL acoustic gw detector would uniquely cover the kHz band, giving “assured” and, in conjunction with advanced interferometers, “confident” detections of the whole dynamics of coalescence of compact binaries.

1. Introduction

It is expected that it would be increasingly difficult to detect gravitational waves as their frequency f gets higher in the kHz region. On one side dimensional arguments on maximal quadrupole emission give amplitudes that characteristically decrease as $1/f$, and on the other side at their Standard Quantum Limit both “bars” for given materials and “interferometers” in wideband configuration, would systematically have the intrinsic spectral noise increase with f .

At low frequencies, below some 500 Hz, the inspiral phases of neutron stars and black-holes binaries are expected to give gw “chirps”, comfortable enough in amplitude and rate to let “advanced” interferometers of 2013 timeframe enter a phase of steady observations.

At higher frequencies, kHz, violent events in compact sources occur, and gw waveforms are emitted under a mix of fully non linear General Relativity and Equation Of State of superdense matter [1]. As the physics is so much interesting, as one may probe *directly* the dynamics of black-holes and neutron stars in such extreme regimes, we are strongly motivated to continue working with acoustic gw detectors, which most naturally cover the kHz band and may well come out to be the most performing.

Currently we operate in wider bandwidth, ~ 100 Hz, around ~ 900 Hz the “bar” detector AURIGA [2] and recently we made use of its stationary-gaussian behavior to get relevant upper limits on a recent violent event in the Galaxy [3]. For the 2013 time frame we propose the realization of a new kind of acoustic gw detector, the so called DUAL [4-5], which promises a full open band of many kHz, with a low enough noise floor to reach out to bright gw sources in the cosmos.

2. AURIGA and the Dec. 27 giant X-ray flare of SGR 1806-20

The “bar” gw detector AURIGA, in its second run started on Dec 2nd 2004, is in continuous operation, thermal noise limited at 4.5 K, with a noise floor $S_{hh}^{1/2} < 4 \cdot 10^{-21} \text{ Hz}^{-1/2}$ over 90 Hz band (one sided) [2].

Except 3 hours/month for liquidHe transfer it gives $\sim 100\%$ usable data. If we veto time intervals under out-of-band triggers by selecting against epochs of external disturbances to obtain *stationary gaussian* operation for burst observation with no more than ~ 10 outliers/day, then the duty cycle reduces to $\sim 98\%$.

On Dec 27th 2004 the soft gamma ray repeater SGR1806-20, at a 15 Kpc distance in the direction of Sagittarium, gave a giant X-ray flare some 100 times more energetic than any previous[6]. The X-ray flare, after peaking with ms rise time, decayed to 1/10 intensity in ~ 300 ms. A leading model for such an event is a catastrophic instability involving global crustal failure in a “magnetar”[7]. Such a “starquake” would possibly trigger the excitation of f- and p-modes in the neutron star, which in turn would damp out by gw emission with an energetics ~ 100 times larger of that of the X-rays flare [8-9].

At the time of the flare AURIGA was optimally oriented towards SGR1806-20 and was covering a ~ 100 Hz band in which neutron star f- and p-modes *may* fall. Thus we searched if, at the flare time, gw emission could be found, as a damped sinusoidal wave train at any frequency f within AURIGA band, with damping time $\tau_s = 100$ ms. We divided the band in bins of width $\Delta f = 1/2\tau_s = 5$ Hz around each f , integrated for a time $\Delta t \sim \tau_s$, the output energy e in the sub-band, checked the statistics of the time series $\square(t)$ in each sub-band f , searched for any excess in $\square(t)$ at the flare peak time.

The search was negative in all the 5 Hz frequency bins in the interval 850-950 Hz, so we put upper limits on the gw energy, as a fraction of solar mass ε_{gw} , emitted in each bin.

The existing models predict $\varepsilon_{gw} \sim 5 \cdot 10^{-6}$ [8-9]. Our upper limits depend on the bin as there is some variability of sensitivity as a function of frequency. The upper limits at 95% confidence level span values $\varepsilon_{gw} \sim 3 \cdot 10^{-6} - 4 \cdot 10^{-5}$, so that they invade part of the parameter region of existing models (for a full account see ref[3]).

When upgraded to operate at 100 mK, AURIGA will have the noise floor decreased by one order of magnitude (in amplitude) on the whole band from 850 Hz to 950 Hz. So, in an event analogous to the Dec 27th 2004 which may be expected in a few years, it would be possible to discover/limit gw emissions of two orders of magnitude lower energetics.

3. From AURIGA to DUAL for the gw sources in the kHz band

The search outlined above is a good example to show the interest, but also the limitations of “bar” detectors, even if so well performing as AURIGA. For instance, even if the upgraded AURIGA may invade crucially the models parameter space in energy, it would cover only a (small) part of the frequency range in which the quasi-normal modes of a neutron star may fall.

A unique possibility is offered by the acoustic detector of new conception called DUAL (see ref [5] for a full description and predicted sensitivities) as it would cover a band from ~ 1 kHz to ~ 5 kHz, with a flat spectral noise floor as low as $7 \cdot 10^{-24} \text{ Hz}^{-1/2}$.

Ref [1] gives an excellent overview of the gw sources expected at such high frequencies. Given the predicted gw amplitudes in ref [1], DUAL would see a variety of gw signals produced by newborn neutron stars, ms pulsars, LowMassX-rayBinaries. DUAL would also see out to the Virgo Cluster those Supernovae, which involve the core collapse of fast rotating stars, as, according to ref [10], “bar” instabilities would set up, delivering at $f \sim 1$ kHz gw of considerably larger amplitudes than axisymmetric collapse.

Here we bring attention to the most bright sources, after the prediction of their gw waveforms received most recently a significant progress, because they can be seen as the reference sources for a confident detection by a combination of a hybrid network of interferometric and acoustic detectors.

As two neutron stars merge, at the end of the inspiral phase of a binary, quasi-periodic gw of large amplitude, several 10^{-21} out to 100 Mpc, are emitted from a hypermassive neutron star, lasting some 100 ms, before collapse to a black-hole and the frequency would be $f \sim 3-4$ kHz depending on EOS [11]. It is worth noticing that the merger of ns-ns binaries is connected with increasing confidence to short gamma-ray bursts [12]. At a threshold total mass in the range 2.5-2.7 solar masses, depending on

EOS, the system would rather form promptly a black-hole, which would vibrate at ~ 7 kHz, with total energy at most $\sim 1\%$ of the initial total mass of the system [11].

As two “stellar” black holes inspiral to plunge, merge and ring-down, they would be strong gw emitters, the ring-down being at high frequencies for initial total mass smaller than some 25 solar masses. The merger should give some 5% of the initial total mass in gw, thus as much as ~ 1 solar mass for a typical 10+10 solar masses system, for which the frequency of the strongly damped mode would be ~ 1 kHz [13-14].

Both kind of sources would be seen at a rate $> 3/y$ out to $> 100\text{Mpc}$, by an “advanced” interferometer and by a DUAL.

4. Concluding remarks

Occasionally a compact binaries inspiral+merger event could be seen by hybrid networks of currently operating interferometers and upgraded bars, as AURIGA.

For the > 2013 timeframe, one can envisage a comforting detection scenario. The “advanced” interferometers would see mostly the inspiral phase and predict from its features the time of plunge, then the DUAL would detect at the right time the merger signal. This would be an “assured” steady rate of signals seen by the hybrid observatory, which, given the strong signature, would result in confident assignments to gw events.

References

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