Summary

In this meeting several aspects of the structure and dynamics of neutron stars (NS) have been discussed, which are relevant to the emission of gravitational waves to be detected by ground-based experiments (LIGO and VIRGO, their advanced versions, and the Einstein Telescope ET which is now in the commissioning phase).

The physics of NS is multidisciplinary, since it involves nuclear physics, magnetohydrodynamics, numerical relativity, astrophysical observations and source modelling; main experts in these fields have been invited to meet and discuss.

The workshop consisted of three days of discussions on various topics related to neutron stars as gravitational wave sources. Following the spirit of previous NSDN meetings, after each talk much time was left to discussions, which were very interesting and stimulating.

As a consequence of this intense interaction, the following processes involving NS have emerged as being extremely important, either because they are expected to occur with a high rate and to emit a strong gravitational signal, or because they are expected to be accompanied by an electromagnetic counterpart which can facilitate detection:

- Coalescing binaries
- Magnetars
- Accreting neutron stars

Other topics were also discussed, like the equation of state of neutron stars and the properties of rotating neutron stars.

The list of participants and other information can be found at the meeting website, `www.neutronstars.net78.net` , where the pdf files of the presentations will soon be available.

Description of the scientific content and discussion at the event

The meeting consisted of three days of discussions on various topics related to neutron stars as gravitational wave sources. Following the spirit of the previous NSDN meetings, 25' were allocated to each talk and 15' were left for discussions.

The talks presented in the meeting are the following:

Tuesday	**April** 21^{st}
L. Stella:	Recent astrophysical results on gravitational wave sources
A. Papitto:	The inner disc radius of an accreting ms pulsar
A. Watts:	Gravitational waves from accreting neutron stars
S. Yoshida:	Accretion torus with azimuthal and meridional flow
O. Benhar:	Unified description of equation of state and transport properties of neutron star matter
A. Sedrakian:	Gravitational waves from hybrid stars
Wedsneday:	**April** 22^{nd}
G. Israel:	Recent results on transient phenomena of magnetars
A. Colaiuda:	On QPOs in magnetars
S. Lander:	Poloidal and toroidal fields in axisymmetric neutron stars
R. Ciolfi:	Twisted-torus magnetic field configurations in relativistic magnetars
E. Bozzo:	Hunting for magnetars in binary systems

B. Giacomazzo:	Gravitational waves from binary neutron stars
S. Dall'Osso:	Newly born magnetars as GW sources: an astrophysical perspective
E. Gaertig:	Oscillations of rapidly rotating stars
G. Corvino:	Bar-mode instability of differentially rotating neutron stars with realistic equation of state
F. Galeazzi:	Modeling differentially rotating hypermassive neutron stars as remnants of binary neutron star mergers

Thursday:	**April** 23^{rd}
D. Guetta:	Gravitational waves from short gamma-ray bursts
T. Bulik:	Masses and mass ratios of DNS binaries
J. Read:	Tidal deformation in binary neutron star inspiral
F. Pannarale:	A semi-relativistic model of tidal interactions in black hole - neutron star coalescing binaries
C. Peralta:	Gravitational waves from hydrodynamic turbulence in a neutron star
E. Abdikamalov:	Accretion-induced collapse of white dwarfs

The first day, L. Stella presented a survey on recent astrophysical results obtained at the astronomical observatory of Rome and relevant to gravitational wave sources, with special attention to magnetars and short gamma-ray bursts.

Then, the discussion focused mainly on the emission processes of accreting neutron stars; A. Papitto reported results obtained by XMM-Newton concernig the innermost region of the accretion disc radius around a fast pulsar; A. Watts discussed about gravity wave emission in spin-balance and in spin-down scenarios; S. Yoshida presented a thick torus model with meridional flow around a compact object.

There were two talks about the neutron star equation of state: O. Benhar presented a unified approach to describe the equation of state and the dissipative properties of neutron stars; A. Sedrakian discussed about neutron stars with a superconducting quark-matter core.

The second day the discussion mainly focused on the magnetic field of neutron stars. G. Israel and E. Bozzo reported recent astrophysical data on magnetars; A. Colaiuda described a model of oscillating magnetars, which is relevant to understand the QPOs

observed in giant flares; S. Lander and R. Ciolfi discussed stationary configurations of magnetars with a twisted-torus magnetic field, showing that in this models the poloidal field is likely to dominate on the toroidal field; B. Giacomazzo reported on numerical simulations of binary neutron star coalescence with strong magnetic fields; S. Dall'osso discussed astrophysical perspectives of newly-born magnetars.

Then, the issue of rotating neutron stars was discussed. E. Gaertig presented a model of oscillating rapidly rotating stars, finding the effect of rotation on the quasi-normal modes; G. Corvino discussed the bar-mode instability of differentially rotating neutron stars; F. Galeazzi discussed the properties of differentially rotating hypermassive neutron stars.

The main discussion topic of the third day was binary coalescences and short gamma-ray bursts as gravitational wave sources. D. Guetta discussed compact binaries dynamically formed in globular clusters; T. Bulik discussed the present state of knowledge about neutron star masses and mass ratios in binaries; J. Read and F. Pannarale discussed tidal deformations in neutron star-neutron star coalescing binaries and in black hole-neutron star coalescing binaries, respectively, showing how they affect the gravitational wave emission of these sources.

Finally, C. Peralta discussed the gravity wave emission due to hydrodynamical turbulence in neutron stars, and E. Abdikamalov discussed the accretion-induced collapse in white dwarfs, as an alternative to the stellar explosion associated with type Ia supernovae.

Assessment of the results and impact of the event on the future direction of the field

In this meeting we have discussed several aspects of the dynamics of neutron star (NS), which are expected to be among the main sources of gravitational waves (GW) to be detected by ground-based experiments (LIGO and VIRGO, their advanced versions, and the Einstein Telescope ET which is now in the commissioning phase).

Since the physics of NS is multidisciplinary (it involves nuclear physics, magnetohydrodynamics, numerical relativity, astrophysical observations and source modelling), we have invited many of the main experts in these fields, to meet and discuss. The contamination of different fields has been very useful and fruitful, and a deeper understanding of these complex phenomena is a main result of this meeting.

The following processes involving NS have emerged to be extremely important, either because they are expected to occur with a high rate and to emit a strong gravitational signal, or because they are expected to be accompanied by an electromagnetic counterpart which can facilitate detection.

Coalescing binaries

Coalescing binaries, involving either two NS or a NS and a black hole, are expected to be the main source of GW for ground-based detectors. The event rate is sufficiently high for detection, and, as emerged in the meeting, if one considers also the compact binaries dynamically formed in globular clusters, such rates increase.

Furthermore, coalescing compact binaries are likely to be the progenitors of short gamma-ray bursts, which would provide us with an electromagnetic counterpart of the gravitational signal, thus facilitating the detection of GW.

Coalescing compact binaries can be studied with various approaches. Great advances in numerical relativity have recently allowed the detailed modelling of such systems, including rotation, non-polytropic equations of state, magnetic fields. Numerical relativity is complemented by post-Newtonian approaches, which has recently been extended to include the tidal deformation of the star, either parametrized with the so-called "Love numbers", or described

within the "affine approximation", in which the star is assumed to maintain an ellipsoidal shape.

Magnetars

The main part of the conference has been devoted to the study of strongly magnetized NS. Recent astrophysical observations have shown that around 10% of NS become magnetars, acquiring a surface magnetic field of the order of $10^{14} - 10^{15}$ G. This field is likely to be formed in the early stages of the life of the star, and to have a significant toroidal component.

The main reasons of interest in magnetars are the following:

- Recent astrophysical observations have shown neutron star oscillations in the outburst of giant flares of magnetars. This is the only case of observed neutron star oscillations, thus it provides a unique opportunity to understand the structure and oscillations of NS. For this reasons, a great effort is dedicated to modelling the oscillations of strongly magnetized stars. As discussed in the meeting, the most recent models could account for most of the observed oscillation modes.

- If the toroidal component dominates, the star may acqquire a prolate shape. If this happens, then a "spin-flip" may occur, and the star may change its rotation axis, becoming a strongly non-axisymmetric object which emits a huge amount of GW. It is then of utmost importance to understand the structure of the internal magnetic field in magnetars. Preliminary results seem to indicate that the field is prevalently poloidal (and then that the spin-flip scenario is unlikely), but this issue deserves further investigation and more accurate models.

Accreting neutron stars

In recent years, accreting NS have been considered among the most promising sources of GW. The idea is that accretion should induce the spin-up of the star, but we observe that this does not occur; therefore, a dissipation mechanism is needed to explain the observed spin balance. First estimates had shown that if (as it is commonly believed) this dissipation mechanism is GW emission, such emission should be detectable by the advanced versions of LIGO and VIRGO.

As emerged in the meeting, the most recent estimates, which take into account the present parameter uncertainty, show that the detection of GW related to spin balance by LIGO, VIRGO and even by ET is unlikely. On the other hand, other scenarios have been proposed, in which the accreting star spins down, yielding a stronger GW emission.

NSDN Meeting
Neutron stars as gravitational wave sources
21-23 April 2009

Program

Following the spirit of the previous NSDN meetings,
the talks should be aimed to stimulate the discussion.
Each talk, of $\sim 25'$, will be followed by $\sim 15'$ of discussion.

Tuesday **April** 21^{st}

11.00-11.10:
V. Ferrari: Welcome

11.10-12.30:
L. Stella: Recent astrophysical results on gravitational wave sources
A. Papitto: The inner disc radius of an accreting ms pulsar

12.30-14.00 Lunch

14.00-15.20:
A. Watts: Gravitational waves from accreting neutron stars
S. Yoshida: Accretion torus with azimuthal and meridional flow

15.20-15.50 Coffee break

15.50-17.10:
O. Benhar: Unified description of equation of state and transport properties of neutron star matter
A. Sedrakian: Gravitational waves from hybrid stars

Wedsneday: **April** 22^{nd}

9.30-10.50:	
G. Israel:	Recent results on transient phenomena of magnetars
A. Colaiuda:	On QPOs in magnetars
10.50-11.15	Coffee break
11.15-12.35:	
S. Lander:	Poloidal and toroidal fields in axisymmetric neutron stars
R. Ciolfi:	Twisted-torus magnetic field configurations in relativistic magnetars
12.35-14.00	Lunch
14.00-16.00:	
E. Bozzo:	Hunting for magnetars in binary systems
B. Giacomazzo:	Gravitational waves from binary neutron stars
S. Dall'Osso:	Newly born magnetars as GW sources: an astrophysical perspective
16.00-16.30	Coffee break
16.30-18.30:	
E. Gaertig:	Oscillations of rapidly rotating stars
G. Corvino:	Bar-mode instability of differentially rotating neutron stars with realistic equation of state
F. Galeazzi:	Modeling differentially rotating hypermassive neutron stars as remnants of binary neutron star mergers

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9.30-10.50:	
D. Guetta:	Gravitational waves from short gamma-ray bursts
T. Bulik:	Masses and mass ratios of DNS binaries
10.50-11.15	Coffee break
11.15-12.35:	
J. Read:	Tidal deformation in binary neutron star inspiral
F. Pannarale:	A semi-relativistic model of tidal interactions in black hole - neutron star coalescing binaries
12.35-14.00	Lunch
14.00-15.20:	
C. Peralta:	Gravitational waves from hydrodynamic turbulence in a neutron star
E. Abdikamalov:	Accretion-induced collapse of white dwarfs
15.20-15.50	Coffee break
15.50-16.10:	
V. Ferrari, L. Gualtieri, L. Stella	Farewell