Editorial on the GRG special issue on “Gravitational waves detection with atom interferometry”

G. M. Tino · F. Vetrano · C. Lämmerzahl

Published online: 26 May 2011
© Springer Science+Business Media, LLC 2011

This year 2011 marks the 20th anniversary of atom interferometry. It started with microfabricated mechanical beam splitters, namely double slits as used by Carnal and Mlynek [1] and gratings used by the group of Pritchard [2]. A few months later the first atom interferometers based on laser beams as beam splitters and mirrors have been built by Riehle et al. [3] and Kasevich and Chu [4]. After the first demonstration of their functioning these atom interferometers using laser beams as optical elements have been improved to become sensitive accelerometers and gyroscopes as has been first proposed by Bordé [5] as well as tools for various fundamental physics experiments (see, e.g., the reviews [6,7]).

The impressive development in matter wave interferometry with neutral atoms is stimulating an increasing interest on the idea to use atom interferometers even to detect the elusive gravitational waves. The first workshop on Gravitational Waves Detection with Atom Interferometry was held in Florence, Italy, in 2009 [8]. This special issue derives from that workshop and collects papers by the groups actively working in

G. M. Tino (✉)
Dipartimento di Fisica e Astronomia and LENS-Università di Firenze,
INFN-Sezione di Firenze, Polo Scientifico, 50019 Sesto Fiorentino, Italy
e-mail: guglielmo.tino@fi.infn.it

F. Vetrano
Dipartimento di Matematica, Fisica e Informatica-Università di Urbino,
INFN-Sezione di Firenze, 61029 Urbino, Italy
e-mail: flavio.vetrano@uniurb.it

C. Lämmerzahl
ZARM, University Bremen, Am Fallturm, 28359 Bremen, Germany
e-mail: laemmerzahl@zarm.uni-bremen.de

C. Lämmerzahl
Institute for Physics, University Oldenburg, 26111 Oldenburg, Germany

this direction both from the experimental and the theoretical point of view. In 2010, a second workshop on this subject was held in Hangzhou, China [9].

Direct detection of gravitational waves is one of the most exciting scientific challenges of this century: ground based interferometric antennas such as Virgo [10], LIGO [11], and GEO [12] are already running and taking data in a coordinated way while space-based antennas, such as LISA [13], are considered for flying in the future. These large laser interferometers emerged after 30 years of developments from prototypes first built in the mid 70ies in Garching, Glasgow, Tokyo and at Caltech. The gravitational wave spectrum expected from models for astrophysical sources spans many orders of magnitude and in order to investigate it in a complete fashion different types of detectors are needed, having their maximum sensitivities in different frequency bands. The technology of atom interferometers has already reached a very high level of maturity. Therefore it is quite natural to look at this promising field inquiring the possibility to fill the gaps in the frequency spectrum or to improve the sensitivity in some frequency range in order to increase the event rate by enlarging the accessible universe, or trying to handle a new technology that might lead to more compact and less expensive detectors.

In this special issue, several new schemes for atom interferometers, beam splitters and high flux coherent atomic sources are presented and theoretical implications are discussed. In the paper by Hohensee et al. [14], an optimized atomic gravitational wave interferometric sensor is proposed and technical challenges are discussed based on a table-top demonstrator that is presently under construction at Berkeley, USA. The paper by Zhou et al. [15] reports on a 10-m atom interferometer designed for precision gravity measurement and the equivalence principle test which is presently under construction in Wuhan, China. The paper by Yu and Tinto [16] presents the conceptual design of a broad-band detector of gravitational waves that relies on two atom interferometers separated by a distance well larger than the linear dimension of the single interferometer. In the paper by Hogan et al. [17], an atom interferometer gravitational wave detector in low Earth orbit is proposed. Gravitational waves would be observed by comparing a pair of atom interferometers separated by a 30 km baseline. Systematic backgrounds are analyzed that would be relevant to the mission. The paper by Lepoutre et al. [18] discusses the optimization of atom interferometers for rotation and for gravitational waves detection. Various diffraction processes are considered with a focus on Bragg diffraction by a laser standing wave. The paper by Gao et al. [19] also focuses on the possibility of detecting gravitational-waves with matter-wave interferometers using schemes where atom beams are split and deflected by standing light waves. In the paper by Tino and Vetrano [20], a Mach–Zehnder atom interferometer is studied as gravitational wave detector under the hypothesis of shot noise limited sensitivity. As an example, a possible configuration for a specific frequency range is analysed in some detail. The paper by Lorek et al. [21] presents a new scheme for an orientational quantum interferometer sensitive to gravitational waves that is based on orienting quantum objects like molecules, atoms, or nuclei in space. Finally, the paper by Göklü and Lämmerzahl [22] discusses theoretically fluctuations of spacetime and holographic noise in atomic interferometry. Overall the papers in this special issue show the strong interest and the fascinating prospects of this emerging field of research.

References

1. Carnal, O., Mlynek, J.: Young's double-slit experiment with atoms: a simple atom interferometer. *Phys. Rev. Lett.* **66**, 2689 (1991)
2. Keith, D.W., Ekstrom, C.R., Turchette, Q.A., Pritchard, D.E.: An interferometer for atoms. *Phys. Rev. Lett.* **66**, 2693 (1991)
3. Riehle, F., Kisters, Th., Witte, A., Helmcke, J., Bordé, Ch.J.: Optical Ramsey spectroscopy in a rotating frame: Sagnac effect in a matter-wave interferometer. *Phys. Rev. Lett.* **67**, 177 (1991)
4. Kasevich, M., Chu, S.: Atomic interferometry using stimulated Raman transitions. *Phys. Rev. Lett.* **67**, 181 (1991)
5. Bordé, Ch.J.: Atomic interferometry with internal state labeling. *Phys. Lett.* **A140**, 10 (1989)
6. Berman, P.R. (ed.): *Atom Interferometry*. Academic press, London (1997)
7. Cronin, A.D., Schmiedmayer, J., Pritchard, D.E.: Optics and interferometry with atoms and molecules. *Rev. Mod. Phys.* **81**, 1051 (2009)
8. Workshop on Gravitational Waves Detection with Atom Interferometry. Firenze, Italy, 23–24/2/2009. www.ggi.fi.infn.it
9. 2010 International Workshop on Gravitational Waves Detection with Atom Interferometry. Hangzhou, China, 20–22/10/2010. www.e0571pm.com.cn/workshop
10. See the e-address <http://www.virgo.infn.it>
11. See the e-address <http://www.ligo.caltech.edu>
12. See the e-address <http://www.geo600.org/>
13. See the e-address <http://lisa.jpl.nasa.gov>
14. Hohensee, M., Lan, S., Houtz, R., Chan, C., Estey, B., Kim, G., Kuan, P., Müller, H.: Sources and technology for an atomic gravitational wave interferometric sensor. *Gen. Relativ. Gravit.* (this issue) doi:[10.1007/s10714-010-1118-x](https://doi.org/10.1007/s10714-010-1118-x)
15. Zhou, L., Xiong, Z.Y., Yang, W., Tang, B., Peng, W.C., Hao, K., Li, R.B., Liu, M., Wang, J., Zhan, M.S.: Development of an atom gravimeter and status of the 10-meter atom interferometer for precision gravity measurement. *Gen. Relativ. Gravit.* (this issue) doi:[10.1007/s10714-011-1167-9](https://doi.org/10.1007/s10714-011-1167-9)
16. Yu, N., Tinto, M.: Gravitational wave detection with single-laser atom interferometers. *Gen. Relativ. Gravit.* (this issue) doi:[10.1007/s10714-010-1055-8](https://doi.org/10.1007/s10714-010-1055-8)
17. Hogan, J.M., Johnson, D.M.S., Dickerson, S., Kovachy, T., Sugarbaker, A., Chiow, S.W., Graham, P.W., Kasevich, M.A., Saif, B., Rajendran, S., Bouyer, P., Seery, B.D., Feinberg, L., Keski-Kuha, R.: An atomic gravitational wave interferometric sensor in low earth orbit (AGIS-LEO). *Gen. Relativ. Gravit.* (this issue) doi:[10.1007/s10714-011-1182-x](https://doi.org/10.1007/s10714-011-1182-x)
18. Lepoutre, S., Jelassi, H., Tréneç, G., Büchner, M., Vigué, J.: Atom interferometry as a detector of rotation and gravitational waves: comparison of various diffraction processes. *Gen. Relativ. Gravit.* (this issue) doi:[10.1007/s10714-010-1133-y](https://doi.org/10.1007/s10714-010-1133-y)
19. Gao, D., Ju, P., Zhang, B., Zhan, M.: Gravitational-wave detection with matter-wave interferometers based on standing light waves. *Gen. Relativ. Gravit.* (this issue) doi:[10.1007/s10714-011-1173-y](https://doi.org/10.1007/s10714-011-1173-y)
20. Tino, G.M., Vetrano, F.: Atom interferometers for gravitational wave detection: a look at a “simple” configuration. *Gen. Relativ. Gravit.* (this issue) doi:[10.1007/s10714-010-1139-5](https://doi.org/10.1007/s10714-010-1139-5)
21. Lorek, D., Wicht, A., Lämmerzahl, C.: A new type of quantum interferometer for gravitational wave detection. *Gen. Relativ. Gravit.* (this issue) doi:[10.1007/s10714-010-1042-0](https://doi.org/10.1007/s10714-010-1042-0)
22. Göklü, E., Lämmerzahl, C.: Fluctuations of spacetime and holographic noise in atomic interferometry. *Gen. Relativ. Gravit.* (this issue) doi:[10.1007/s10714-010-1137-7](https://doi.org/10.1007/s10714-010-1137-7)