Electromagnetic Counterparts to Gravitational Waves and the case of GRB 170817A

Alberto J. Castro-Tirado[1,2,*], Youdong Hu[1], Binbin Zhang[3], and Vladimir Sokolov[4]

[1]*Instituto de Astrofísica de Andalucía (IAA-CSIC), P.O. Box 03004, E-18080 Granada, Spain; ajct@iaa.es*

[2]*Departmento de Ingeniería de Sistemas y Automática (Unidad Asociada al CSIC), Escuela de Ingeniería Industrial, Universidad de Málaga, Spain*

[3] *University of Nanjing, China*

[4]*Special Astrophysical Observatory (SAO-RAS), Zelenchuk, Karachai-Cherkessia, Russia*

Abstract We briefly report on detection of the first electromagnetic counterpart for GW 170817A. Thanks to it, the new Era of Gravitational Wave Astronomy has just been opened in 2017.

Keywords: Gravitational Wave, Short-duration Gamma-Ray Bursts, Multimessenger Astronomy

1. Introduction

The detection of gravitational waves (GWs) from a coalescing black hole binary system has been one of the major discoveries in this 21st century (Abbott et al. 2016) and will become more common from high energy celestial sources, cosmic explosions and astrophysical transients when a worldwide network of advanced versions of ground-based GW interferometers will become operational within the frequency range from 10 Hz to a few kHz within the coming years. Furthermore, the recent detection of the first GW counterpart at electromagnetic wavelengths (GW 170817) opened the new era of multi-messenger Astronomy in 2017. For the first time, this shed light on three open issues that remained obscure until that time: 1) electromagnetic counterparts can be detected for at least a fraction of GW alerts related to neutron stars (NS) mergers (Abbott et al. 2017 and references therein); 2) short duration gamma-ray bursts arise in these NS-NS mergers (see for instance Zhang et al. 2018) and 3) heavy elements (heavier than Fe) are produced in this sites due to the r-process nucleosynthesis (Pian et al. 2017).

2. Observational facts

Besides these superb discoveries reported in 2015-17 representing the first single accomplished direct test of general relativity, the detection of GWs allows to probe the inner regions of many astrophysical phenomena that are otherwise inaccessible to investigation and provide unique information on their emitters such as the two black holes (BH) merger for

GRB150914 or the NS-NS merger for the GW 170817. Other promising GW emitter candidates are the mergers of binary systems hosting two neutron stars or a NS-BH (Belczynski et al. 2008; Berger 2014) if they occur in the local Universe. The frequency of neutron star mergers is estimated at ~40 per year within 200 Mpc (Abadie et al. 2010; Singer et al. 2014; Kasliwal & Nissanke 2014).

The multi-wavelength imaging of a GW source is made extremely arduous by the size of the error areas expected to be returned by the interferometers. These are dozens to hundreds of square degrees, and only cameras with very large fields of view can cover entirely in one shot or with a small number of tiled pointings.

The monitoring of the confirmed NS-NS counterparts from early to late time is most essential, in order to properly sample the lightcurve and especially, monitor the evolving spectra. An NS-NS merger, accompanied by a short GRB first, and the emergence of so-called kilonova emission after, is expected to be accompanied by production of heavy r-process elements (Barnes & Kasen 2013; Bauswein et al. 2013) as seen in GW170817, and this translates into a transient signal that should peak hours after explosion at an expected optical absolute magnitude $M_v = 17$, and decrease thereafter with a timescale set by the diffusion time: the decline is faster for lower ejecta masses and higher energies.

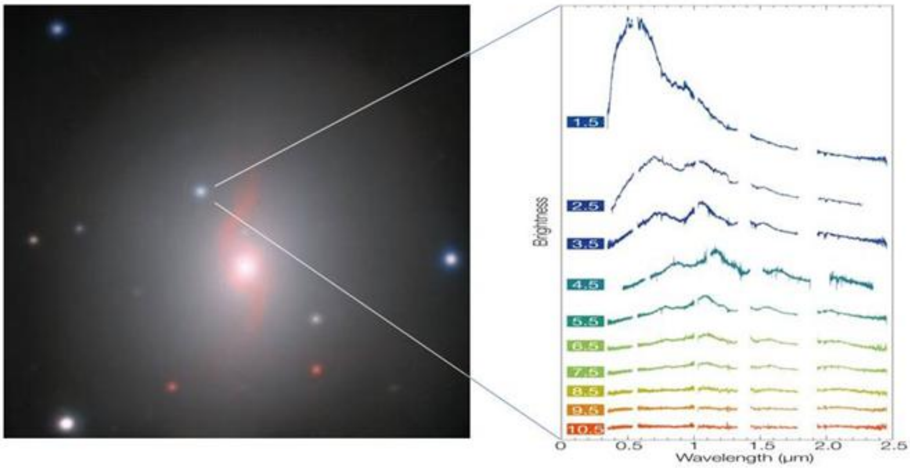

Fig1. *Left: The NGC 4993 galaxy at 40 Mpc including the optical counterpart to GW170817 following the short-duration gamma-ray burst GRB 170817A/ Right: the spectroscopic monitoring revealing the macronova (dubbed AT2017gfo) evolution for the first 11 days. From these observations, the existence of the r-process nucleosynthesis was inferred. As the ejecta expands, broad absorption-like lines appear on the spectral continuum, including atomic species produced by nucleosynthesis that occurs in the post-merger fast-moving dynamical ejecta and in two slower (0.05 times light speed) wind regions. Comparison with spectral models suggests that the merger ejected 0.03 to 0.05 solar masses of material, including high opacity lanthanides. Adapted from Pian et al. (including Castro-Tirado) 2017.*

The evolving spectra (complemented by NIR observations to properly model the kilonova Rayleigh-Jeans tail) is of utmost importance in order to search for the lanthanide-rich or lanthanide-free ejecta which may be present in heavy element production. Other candidates for GW in the range of frequencies accessible to ground based interferometers include also long GRBs (Corsi & Meszaros 2009), core-collapse supernovae (Ott et al. 2012; Muller et al. 2012), newly born magnetars (Stella et al. 2005; Dall Osso et al. 2009), and magnetars (Corsi & Owen 2011; Abadie et al. 2011).

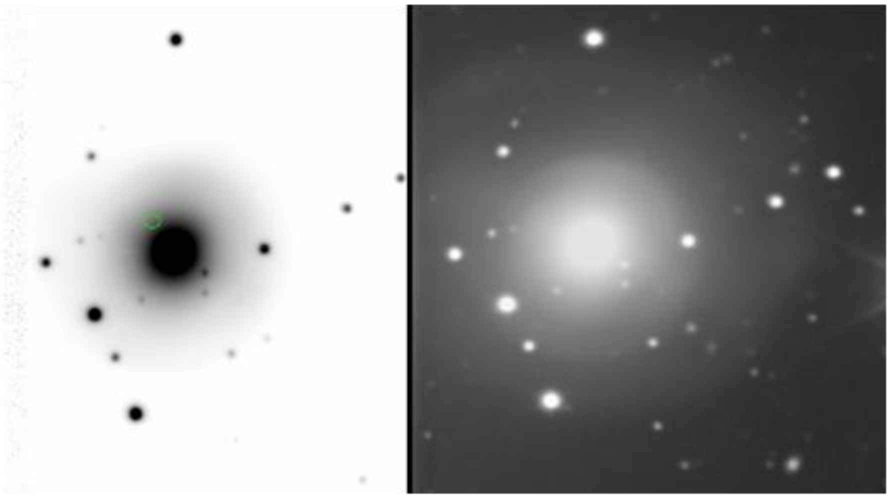

Fig2. *NGC4993 (1200s, Sloan i'-band filter) was maged by the 10.4m GTC on 19 Jan 2018, ~5 months agfter the occurrence of GW 170817A. Left: the location of the NS-NS merger (the green circle) is shown. Right: the image has been processed to show the different stellat shells around the galaxy. Adapter from Pandey, Hu, Castro-Tirado et al. (2019).*

3. Conclusions

The new Era of Gravitational Wave Astronomy has just been opened. With the advent of the forthcoming advanced LIGO-VIRGO Observing Run 3 (O3) in Apr 2019, the numbers of GW alerts will significantly increase. Coordinated multiwavelength efforts will shed light into the physics of compact objects mergers in the Universe.

Acknowledgements

We acknowledge fruitful discussions with the rest of the ARAE and BTA teams. On the IAA-CSIC side, the project is funded by the Spanish Ministry's projects AYA 2012-39727-C03-01 and AYA2015-71718R, and the Junta de Andalucía's project TIC-2839.

References

[1] Abbott, B. P. et al. 2016, Physical Review Letters, 116, 061102.

[2] Abbott, B. P. et al. 2017, ApJL 848, 12

[3] Abbott, B. P. et al. 2018, http://adsabs.harvard.edu/abs/2018LRR....21....3A

[4] Abadie, J., et al., 2010, ApJ, 734, L35.

[5] Bauswein, A., et al., 2013, Physical Review Letters, 111, 131101.

[6] Barnes, J., & Kasen, D., 2013, ApJ, 775, 18.

[7] Belczynski, C., et al., 2008, ApJ, 682, 474.

[8] Berger, E., et al., 2013, ApJ, 774, L23.

[9] Berger, E., 2014, ARA&A, 52, 43.

[10] Castro-Tirado, A. J. et al., 2017, GCNC, 21624.

[11] Corsi, A., & Owen, B.J., 2011, Phys. Rev. D, 83, 104014.

[12] Dall ´Osso, S., et al., 2009, MNRAS, 398, 1869.

[13] Falta, D., et al., 2011, Phys. Rev. Lett., 106, 201103.

[14] Kasliwal, M., & Nissanke, S., 2014, ApJ, 789, L5.

[15] Mueller, E., et al., 2012, A&A, 537, 63.

[16] Ott, C., et al., 2012, Phys. Rev. D, 86, 024026.

[17] Pandey, S. B., Hu,Y.-D., Castro-Tirado, A.J. et al. 2019, MNRAS, in press (arXiv:1902.07900)

[18] Pian, E. et al. 2017, Nat 551, 67.

[19] Pankow, C. 2018, private comm. at the LVC MIT Town Hall meeting, March 2018

[20] Perna, R. et al. 2018, MNRAS 477, 4228.

[21] Singer, L., et al., 2013, ApJ, 776, L34.

[22] Singer, L., et al., 2014, arXiv:1404.5623.

[23] Stella, L., et al., 2005, ApJ, 634, L165.

[24] Tanvir, N., et al., 2013, Nature, 500, 547.

[25] Zhang, B.-B. et al. 2018, Nat Co 8, id. 447.