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A new set of radiative decay rates for forbidden lines in lanthanide ions of interest for kilonova nebular phase studies

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On August 17, 2017, the LIGO/Virgo collaboration detected for the first-time a gravitational waves signal (GW170817) associated with a neutron star merger [1]. Following the merger, a large quantity of matter was projected. It was shown that this ejecta was the site of nuclear reactions producing chemical elements heavier than iron such as lanthanides (Z = 57-61) [2]. The hot and radioactive material produced a transient electromagnetic phenomenon called kilonova [3]. More recently, in March 2023, astrophysicists detected a gamma ray burst associated with what could be a merger of compact objects followed by a transient afterglow. After analysing the spectra, they found some similarity with the AT2017gfo kilonova spectra suggesting the presence of such phenomena. The particularity with this kilonova event is that the spectrum has been recorded, by the Near Infrared Spectrograph (NIRSpec) onboard the James Webb Telescope (JWST), at late time after the merger [4]. At these times, the kilonova is said to be in his nebular phase. Conditions are such that the temperature is really low and the ionization stage does not exceed the doubly charged species. Only low-lying levels, such as metastable levels, are populated giving rise to so-called emission forbidden lines, such as the magnetic dipole (M1) and electric quadrupole (E2) transitions. So, for example, the analysis of the late time spectrum showed some spectral features coming from forbidden transitions of heavy elements like Te III [5]. Element identification in nebular phase spectra is quite challenging since atomic data and especially forbidden line lists for heavy elements are scarce in the literature.

In order to extend the study of kilonovae in their nebular phase, we carried out new calculations of transition probabilities for M1 and E2 lines between low-lying levels in singly and doubly ionized lanthanide atoms. Given the lack of data in the literature, two theoretical methods were used in this work to model the atomic structure of these ions and to compute the radiative parameters. The first one is the fully-relativistic Multi-Configurational-Dirac-Hartree-Fock (MCDHF) method [6] with the GRASP2018 code [7]. The computed values were then compared to the results deduced from pseudo-relativistic Hartree-Fock (HFR) calculations [8] in order to check their reliability. This allowed us to obtain a new consistent set of atomic data allowing astrophysicists to study the infrared spectrum of kilonovae in their nebular phase.

[1] B. P. Abbott, *et al.*, Phys. Rev. Lett. **119**, 161101 (2017).
[2] E. Pian, *et al.*, Nature **551**, 67-70 (2017).
[3] B. D. Metzger, Living Rev. Relativ. **20**, 3 (2017).
[4] J. H. Gillanders, *et al.,* arXiv e-print: arXiv:2308.00633 (2023).
[5] A. Levan, *et al.*, arXiv e-print: arXiv:2307.02098v1 (2023).
[6] I. P. Grant, *"Relativistic quantum theory of atoms and molecules: theory and computation*", New-York: Springer (2007).
[7] C. Froese Fischer, *et al.,* Comput. Phys. Commun. **237**, 184 (2019).
[8] R. D. Cowan, "*The theory of atomic structure and spectra*", Berkley: University of California Press (1981).