

Comment on “Efimov States and Their Fano Resonances in a Neutron-Rich Nucleus”

In a three-body model for ^{20}C (neutron—neutron— ^{18}C), Mazumdar *et al.* [1] have recently claimed that a bound Efimov state [2] turns into a continuum resonance when the ^{19}C binding is varied. They also point out this result as due to the mass difference of the particles. Such claims need to be more deeply investigated, as they apparently conflict with previous studies of Efimov physics with three equal-mass particles [3,4].

The Efimov effect is strictly valid in the zero-range limit [2], when the scattering lengths are much larger than the effective range. So, it is appropriate to consider zero-range models as in [5,6]. Within our renormalized zero-range approach, we show that the results obtained for the $n - n - ^{18}\text{C}$ trajectory of Efimov states are consistent with previous studies that have used separable interactions [3,4]. As the unitarity cuts in the complex energy plane come from the $n - ^{19}\text{C}$ elastic scattering and the three-body breakup, we extended the bound-state equations to the second energy sheet through the $n - ^{19}\text{C}$ elastic scattering cut, by using the method given in [7]. Our results, for varying $E_{^{19}\text{C}}$ binding, with the $n - n$ virtual-state energy ($= -143$ keV) and three-body ground-state ($E_{^{20}\text{C}}^{\text{gs}} = -3.5$ MeV) fixed, are shown in Table I. In contrast with [1], no three-body resonances were found.

We also checked that the $n - ^{19}\text{C}$ elastic scattering cross sections for $E_{^{19}\text{C}} = -150, -180,$ and -500 keV, decrease monotonically [8]. The $n - ^{19}\text{C}$ scattering lengths for these three cases are, respectively, 448.5, $-411.3,$ and -8.6 fm (Minus signs are for virtual states). In principle, one can vary the ground state three-body energy [$E_{^{20}\text{C}}^{\text{gs}}$]; however, as shown in Ref. [5] (see also pps. 327–329 of Braaten and Hammer [6]) only the ratios between the two-body energies and three-body ground state energy are enough to determine the first excited Efimov state.

By considering $n - n - c$ three-body systems with asymmetric two-body energies, in [5], a parametric region was mapped, defined by the s -wave two-body (bound or virtual) energies, where Efimov bound states can exist. At the critical boundary, as we increase the two-body (bound or virtual) energies, the Efimov excited energies enter in the second sheet of the complex energy plane as virtual or resonant states (see Fig. 1 of [9]). When at least one of the subsystems is bound, such as $n - ^{18}\text{C}$ in the ^{20}C , they become virtual states, entering the second energy sheet through the $n - ^{19}\text{C}$ elastic cut. This is in agreement with Refs. [3,4]. In order to move the three-body energy

TABLE I. $|E_{^{20}\text{C}} - E_{^{19}\text{C}}|$ excited states for $E_{^{20}\text{C}}^{\text{gs}} = -3.5$ MeV and varying binding $E_{^{19}\text{C}}$. Indices V refer to virtual states.

$ E_{^{19}\text{C}} (\text{keV}) =$	200	190	180	170	160	150	140
$ E_{^{20}\text{C}} - E_{^{19}\text{C}} (\text{eV}) \approx$	668^V	339^V	122^V	14^V	12	115	317

pole from a bound directly to a resonant state, we need a Borromean system (all subsystems unbound) [10]. Such a case [see Fig. 1c of [9]] corresponds to the Innsbruck experiment with Cesium atoms [11].

By introducing a mass asymmetry in a non-Borromean three-body system, without changing the energy relations, the virtual state pole cannot move from the negative real axis of the complex energy plane (with nonzero width) and become a resonance, because the analytical structure of the unitarity cuts remains the same.

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