The authors of the Comment posted under ArXiv [1] have highlighted some points of our work published in Nature [2] that they consider weak or wrong and according to which they conclude that the result of our work is incorrect. The short Comment [1] was followed by a more detailed discussion, authored by A.M.M. alone [3]. We will consider that paper as well in this reply.

We are surprised by the posted Comment also because some of the issues were discussed by some of us with A.M.M. and agreed. We think that the Comment was written in a hasty manner and we can see this from some errors which otherwise have no real explanation. In fact, they refer to this application of the Trojan Horse Method published in Nature as the first one. It is not the first application at all since the method has been applied several times since the early nineties and references therein). The authors of the Comment are perfectly aware of that since two of them have been coauthors of several of our papers. A.M.M. has authored more than 50 papers with THM measurements (dating as early as 2005) and X.T. has authored 7 papers (dating as early as 2013).

1) In our analysis, we did not take the d-24Mg Coulomb interaction into account because, as demonstrated in the pioneering work reported in [15], its effects can be safely neglected. In this paper and in many others authored by A.M.M., many of which are in collaboration with our group, the authors demonstrated that the plane-wave approximation provides the same energy dependence of the three-body cross section as the one obtained using the distorted-wave approximation, but in a much simpler way (yet, significantly departing from the absolute value). This fact is cited, for instance, in [16] (A.M.M. taking care of the theoretical section). Corrections were tested in several papers [27, 28] with the help of A.M.M. himself, proving negligible in our phase space region. Also the pole invariance of the two-body cross section was investigated in different cases [29-31]. It was demonstrated that, within experimental errors, leaving a neutron or a charged particle as spectator to the two body reaction does not affect its energy trend of the two-body cross section.

Our cross section is the result of a high precision experimental work, where the appropriate tests have been performed. In the phase space region populated in our experiment, the 12N beam energy of 30 MeV corresponds to a quite high momentum transfer q_N=500 MeV/c with q defined by the Galilean invariant equation reported in [6], giving an associate de Broglie wavelength of 0.4 fm quite smaller than the 12C+d radius of about 3 fm [10]. This substantiates the peripheral nature of the 14N+12C interaction and the validity of the Impulse Approximation. Moreover, as thoroughly described in the Methods Section of [2], under paragraph “Deuteron Momentum Distribution”, the agreement within experimental errors between the peculiar shape of the experimental deuteron momentum distribution and the theoretical one, clearly indicates that in the phase space region spanned in our experiment the plane-wave approximation can be relied on because no distortions are needed to describe our transfer process in the momentum window spanned in our work. This is consistent with the value of the Sommerfeld parameter for the d+23Mg system, that turns out to be not larger than 1.03, similar to the values obtained in other THM works and in particular in our recent paper on 6Li+19F at 6 MeV published in [13]. After discussion, A.M.M. agreed with us that the d+23Na Coulomb interaction was not crucial. Thus, the general criticism raised by the authors about the need of a general theory does not apply to the present case.

However, the theory developed by A.M.M. was not validated before being applied to the 12C+12C data [9]. The theory appears to fail in reproducing a fundamental aspect that characterizes the transfer process (regardless of its quasi-free nature) and that was observed in all previous experimental works some of them in similar kinematic conditions as our work (such as those published in [16, 18]): for transfer process the deuteron angular distributions are peaked at forward angles. In the region at
backward angles, the reaction cross section is typically dominated by the compound nucleus mechanism with little to no contribution from transfer. One of our referees was an expert of reaction mechanisms and he pretended from us quite a lot of supplemental analysis and material to show him/her unambiguous proof that selected data corresponds to direct $^{12}$C transfer. This is exactly the opposite of what A.M.M. states in his paper [3] and containing the basis of what he claims to be a general theory that uses the distorted-wave-born approximation (DWBA). In that paper A.M.M. states that the deuteron angular distribution from DWBA is peaked at backward angles, completely opposite to the Plane Wave Approach that he criticizes but which gives the forward peak according to experiment. Thus, this is sufficient to consider any application to experimental data, and in particular to $^{12}$C+$^{12}$C ones, to be meaningless. A.M.M. is forgetting that our deuteron cannot go to backward angles being a projectile-like particle. Maybe, this is why A.M.M. re-...
introduced by a single data set. It was recently proved that the use of this data set makes it possible to reduce the systematic error by correcting for the decay branching ratio. Data are compared with the theoretical predictions in the E\(_m\) = 2.5–2.63 MeV region. Thus, again the criticism raised by the authors of the Comment does not apply. Referring to the \(\gamma\)-ray measurements, the comparison with the \(^{20}\text{Ne} + \alpha\) THM data has been done after correcting for the decay branching ratio. Data are all consistent within each other. Of course, new direct measurements are very welcome. The use of many data sets makes it possible to reduce the systematic error introduced by a single data set. It was recently proved in [25] (where A.M.M. is co-author) that having an extended normalization region and using more than one data set for normalization strongly reduce the influence of systematic errors affecting one data set.

3) We thank the authors to recall a fundamental principle of the quantum mechanics of what we are perfectly aware and we are sure our referees and the Editor are also. The normalization region is not affected by wrong J\(^+-\) assignment. The 2.567 MeV state is a J\(^+-\) = 0\(^+\) (see Publisher Amendment). Thus, what is considered a major issue does not apply. As for the odd spin states, whose assignment is taken from literature and done from visual inspection of excitation functions, their spin is uncertain by +/-1. Previous studies cited in [26] give indeed tentative assignment of even neighboring values. Thus, their contribution in the modified R-matrix represents the average behavior of the two neighboring even values.

[1] Mukhamedzhanov A.M., Tang X. & D.Y. Pang, Comments on the \(^{12}\text{C} + \^{12}\text{C}\) fusion S-factor, https://arxiv.org/pdf/1806.05921.pdf.
[2] Tumino A. et al., An increase in the \(^{12}\text{C} + \^{12}\text{C}\) fusion rate from resonances at astrophysical energies. Nature 557, 687 (2018).
[3] Mukhamedzhanov A.M., About \(^{12}\text{C} + \^{12}\text{C}\) fusion astrophysical factor from Trojan horse method, https://arxiv.org/pdf/1806.08828.pdf.
[4] Spitaleri C. et al., The Trojan Horse Method in nuclear astrophysics. Phys. At. Nucl., 74, 1763 (2011).
[5] Tumino A. et al., New Advances in the Trojan Horse Method as an Indirect Approach to Nuclear Astrophysics. Few Body Systems 54, 745 (2013).
[6] Tribble R. et al., Indirect techniques in nuclear astrophysics: a review. Rep. Prog. Phys. 77, Issue: 10 106901 (2014).
[7] Spitaleri C. et al., Indirect \(^{7}\text{Li}(p,\alpha)^{4}\text{He}\) reaction at astrophysical energies. Phys. Rev. C, 60, 055802 (1999).
[8] La Cognata M. et al., Astrophysical S(E) factor of the \(^{13}\text{N}(p,\alpha)^{12}\text{C}\) reaction at sub-Coulomb energies via the Trojan horse method. Phys. Rev. C, 76, 065804 (2007).
[9] La Cognata M. et al., The fluorine destruction in stars: first experimental study of the \(^{19}\text{F}(p,\alpha)^{16}\text{O}\) reaction at astrophysical energies. Astrophysical J., 739, L54 (2011).
[10] Lamia L. et al., An updated \(^{6}\text{Li}(p,\alpha)^{3}\text{He}\) reaction rate at astrophysical energies with the Trojan horse method. Astrophysical J., 768, 65 (2013).
[11] Tumino A. et al., New determination of the \(^{2}\text{H}(d,p)^{3}\text{H}\) and \(^{2}\text{H}(d,n)^{3}\text{He}\) reaction rates at astrophysical energies. Astrophysical J., 785, 96 (2014).
[12] Pizzone R.G. et al., First measurement of the \(^{19}\text{F}(\alpha,p)^{22}\text{Ne}\) reaction at energies of astrophysical relevance. Astrophysical J., 836, 57 (2017).
[13] Spitaleri C. et al., Measurement of the \(^{10}\text{B}(p,\alpha)^{7}\text{Be}\) cross section from 5 keV to 1.5 MeV in a single experiment using the Trojan horse method. Phys. Rev. C, 95, 035801 (2017).
[14] D’Agata G. et al., The \(^{19}\text{F}(\alpha,p)^{22}\text{Ne}\) reaction at energy of astrophysical relevance by means of the Trojan Horse Method and its implication in AGB stars. Astrophysical J. 860, 61-72 (2018).
[15] Dolinsky, E.I., Dzhamalov, P.O., & Mukhamedzhanov, A.M. Peripheral-model approach to stripping into resonant states, Nuclear Physics A, 202, 97 (1973).
[16] Belyaeva T.L. & Zelenskaya N.S., Quasimolecular states in \(^{24}\text{Mg}\) and \(\delta\)-\(\alpha\) angular correlations in the \(^{12}\text{C}(^{14}\text{N},d)^{24}\text{Mg}(\alpha)^{20}\text{Ne}\) reaction, Phys. Rev. C, 66, 034604 (2002).
[17] Belyaeva T.L., Zelenskaya N.S. & Aguero Granados M., Investigation of quasimolecular states in \(^{24}\text{Mg}\) reaction through the analysis of the angular \(\delta\)-\(\alpha\) correlations in the \(^{12}\text{C}(^{14}\text{N},d)^{24}\text{Mg}(\alpha)^{20}\text{Ne}\) reaction. Phys. At. Nucl., 65, 1657 (2002).
[18] Zurmühle R.W. et al., Observation of \(^{12}\text{C}\) cluster transfer by angular correlation measurements. Phys. Rev. C 49, 2549 (1994).
[19] Mazarakis M.G. & Stephens W.E., Experimental measurements of the \(^{12}\text{C} + \^{12}\text{C}\) nuclear reactions at low energies. Phys. Rev. C 7, 1280 (1973).
[20] High M.D., Cujec B., The \(^{12}\text{C} + \^{12}\text{C}\) sub-Coulomb fusion cross section. Nucl. Phys. A, 282, 181 (1977).
[21] Kettner K.U., Lorenz-Wirzba H., Rolfs C., The \(^{12}\text{C} + \^{12}\text{C}\) reaction at subcoulomb energies. Z. Phys. A 298, 65 (1980).
[22] Barrón-Palos L. et al., Absolute cross sections measurement for the \(^{12}\text{C} + \^{12}\text{C}\) system at astrophysically relevant energies. Nucl. Phys. A 779, 318 (2006).
[23] Spillane T. et al., \(^{12}\text{C} + \^{12}\text{C}\) fusion reactions near the Gamow energy. Phys. Rev. Lett. 98, 122501 (2007).
[24] Caughlan G.R. & Fowler W.A., Thermonuclear reaction rates V. At. Data Nucl. Data Tables 40, (1988) 283.
[25] La Cognata M. et al., Updated THM astrophysical factor of the \(^{19}\text{F}(p,\alpha)^{16}\text{O}\) reaction and influence of new direct data at astrophysical energies. Astrophysical J., 805, 128 (2015).
[26] Abegg R. & Davis C.A., \(^{24}\text{Mg}\) states observed via \(^{20}\text{Ne}(\alpha,p)^{22}\text{Ne}\) Phys. Rev. C 43, 6 (1991).
[27] Pizzone R.G. et al., Effects of distortion of the intercluster motion in \(^{3}\text{He}, ^{4}\text{He}, ^{6}\text{Li}\), and \(^{9}\text{Be}\) on Trojan horse motion ("likely to be caused by errors in the energy scales"), as reported in the references cited by the authors of the Comment. By the way, only one point at \(E_{cm} = 2.63\) MeV from the set of [19] enters the normalization with its 35% uncertainty, thus its weight is small. As for the direct measurement by [22], these data have not been used in the normalization since they do not contribute in the \(E_{cm} = 2.5–2.63\) MeV region. Thus, again the criticism raised by the authors of the Comment does not apply. Referring to the \(\gamma\)-ray measurements, the comparison with the \(^{20}\text{Ne} + \alpha\) THM data has been done after correcting for the decay branching ratio. Data are all consistent within each other. Of course, new direct measurements are very welcome. The use of many data sets makes it possible to reduce the systematic error introduced by a single data set. It was recently proved in [25] (where A.M.M. is co-author) that having an extended normalization region and using more than one
applications Phys. Rev. C, 80, 025807 (2009).

[28] Pizzone R.G. et al., Assessing the near threshold cross section of the $^{17}\text{O}(n,\alpha)^{14}\text{C}$ reaction by means of the Trojan horse method. Phys. Rev. C, 95, 025807 (2017).

[29] Tumino A. et al., Validity test of the Trojan Horse Method applied to the $^7\text{Li}+\text{p} \rightarrow \alpha + \alpha$ reaction via the $^3\text{He}$ break-up. Eur. Phys. Jour. A, 27, 243 (2006).

[30] Pizzone R.G. et al., Trojan horse particle invariance studied with the $^6\text{Li}(d,\alpha)^4\text{He}$ and $^7\text{Li}(p,\alpha)^4\text{He}$ reactions. Phys. Rev. C, 83, 045801 (2011).

[31] Pizzone R.G. et al., Updated evidence of the Trojan horse particle invariance for the $^2\text{H}(d,p)^3\text{H}$ reaction. Phys. Rev. C, 87, 025805 (2013).