Improved distances to massive stars in Westerlund 1: towards accurate stellar mass and age measurements.

Abstract

Westerlund 1 is one of the largest clusters in the Milky Way and contains some of the most well-studied blue variable stars and supergiants. Accurate distances to stars are vital to precisely measure their mass and ages. Prior to Gaia, the errors on the distances to stars in Westerlund 1 were large (1 to 5.5 kpc), resulting in uncertainties in the stellar mass of over 54%. Using the Gaia DR2 parallaxes has improved distance uncertainties from 54% to 13%; however, such errors are still too large to accurately measure stellar masses and ages. We propose to use data from Gaia DR3, in conjunction with existing data on stellar temperatures and luminosities, to produce a catalog with the **most accurate distance measurements** to date for massive stars in Westerlund 1. These precise distances will allow us to develop a new database of accurately measured stellar masses and ages of the massive stars in Westerlund 1. This new database will be made publicly available and serve as a *critical* resource for researchers working towards understanding the evolution of supermassive, late-stage stars.

Scientific Justification

Accurate Stellar Masses are Vital Missing Components in our Characterization of Massive Stars in W1

Westerlund 1 is one of the largest clusters in the Milky Way and contains some of the most well-studied blue variable and supergiant stars. Accurate measurements of the properties of these supermassive stars are vital for conducting further research into stellar evolution theory (Aghakhanloo, et. al 2019). In particular, the mass of the star controls the rate at which fuel is consumed. Mass is thus a fundamental parameter that must be well-constrained if stars in Westerlund 1 are to be used as templates of stellar evolution.

To accurately measure the mass of these stars, the star's luminosity and distance must be measured, as the correlation between mass and luminosity are considered to be one of the most fundamental relationships. Therefore, having an accurate distance to the star is imperative. However, our sightline to Westerlund 1 suffers from reddening and extinction, making it difficult to accurately determine the distance to the stars therein (Damineli, et.al 2016). While parallax has given us the ability to get rough distances to the stars in W1, they are highly inaccurate. Gaia has been a game changer for measuring distances due to its two-point measurement system.

Gaia's observations from its nominal mission to its extension has allowed it to observe at least 1% of the Milky Way's population in the near-UV and near-infrared spectrums. Its spectrographic measurements, taken using two telescopes with a fixed measurement of 105.6° between the two lenses while maintaining the same angle to the Sun, allows Gaia to obtain a system of references for measuring distance to the stars it is observing. The longer it does this, the more accurate the distances get. Gaia is 100 times more accurate than its predecessor, Hipparcos. Studying the data released from DR3/DR4 will allow us to determine the age and mass of those stars more accurately for further research by others on stellar evolution.

Therefore, by using a cluster like Westerlund 1 that has a variety of supermassive stars whose distance and luminosity are known can give more information about these late-stage stars. However, prior to Gaia, the errors on the distances to stars in Westerlund 1 were large (1 to 5.5 kpc), resulting in uncertainties in the stellar mass of over 54%. Using the Gaia DR2 parallaxes has improved distance uncertainties from 54% to 13%; however, such errors are still too large to accurately measure stellar masses and ages.

We propose to use data from Gaia DR3 to measure the distances to massive stars in Westerlund 1. This will allow us to create the ***most accurate catalog*** of the stars in this cluster, enabling detailed studies of stellar evolution. This data not only advances ESA's goal of more accurately charting the Milky Way but assists researchers in identifying stars that could go supernova using their mass. This data will be *vital* for years to come, as this new database will be made publicly available and serve as a critical resource for researchers working towards understanding the evolution of supermassive, late-stage stars.

A Muddled View: Obtaining a clear view of Westerlund 1

2.6kpc from Earth is Westerlund 1, a young compact supercluster nearby with a variety of stars at different masses and luminosities. It is even believed that the stars all formed at the same time, over a period of millions of years. However, even with its location, researchers are unable to obtain a clear view to accurately measure the distances to the stars inside due to reddening and extinction that the cluster suffers (Piatti, Bica & Clariá 1998; Clark et al. 2005; Damineli et al. 2016). Gaia has been a gamechanger in determining more accurate distances to the stars; prior to the DR1 release, the distances assumed suffered a 54% margin of error (see figure 1). To better understand the masses of many of the late-stage supermassive stars that are in this cluster, more accurate distances are needed. By looking at the current margin of error that rests at 13%, we know that utilizing the data from the Gaia Data Releases is the best source for either confirming or obtaining more accurate distances. By analyzing the data from DR3 and subsequent DR4 releases, we will create a new catalog of the stars in Westerlund 1, dropping the margin of error further, and therefore allowing for more precise understanding of the mass of Westerlund 1's stars. *(See Figure 1)*

The uncertain distances of Westerlund 1

By targeting Westerlund 1 and comparing the data from the original DR1/DR2 releases to the newest data from the DR3 release and future DR4 datasets, we will be able to determine the distances more accurately to the stars in Westerlund 1. These critical datasets will allow us to lower the current margin of error of 13% to 5% or more, making these datasets key for creating a new model of Westerlund 1. Knowing the distance to Westerlund 1 will help researchers confirm, with the most up-to-date probability, the luminosity, mass, and age of these stars (Aghankhanloo, et.al, 2019).

This more accurate catalog of the supermassive stars in Westerlund 1 will allow researchers to better study the late-stage supermassive stars located in in this cluster, such as hypergiants and the magnetar. Gaia has been on the *forefront* of mapping this section of the Milky Way since the initial DR1 release, making its data vital into creating this updated catalog. Its measurements of astrometry are *unparalleled*, making it not only the obvious choice, but the only choice for this survey. *(See Figure 2)*

Inference and Parallax – Our Best Tools in Tandem with Gaia Data

By analyzing the data from Gaia's DR2, DR3, and upcoming DR4 release, researchers will be able to utilize not only the parallaxes from those releases, but Bayesian inference to minimize the margin of error to the lowest number possible. Initial data shown by Aghankhanloo et.al, in a paper published in 2019 shows that the initial mass for the entire clustering may be less than original hypothesized. Therefore, by re-running the calculations of distance and comparing them to those done by previous researchers, the current distances based off DR2 will either be confirmed or updated.

These updated and/or confirmed distances will be used to create the most accurate catalog of the stars in Westerlund 1. This data is *essential* in understanding the masses of the magnetar CXO J164710.20-455217 and the large blue variable star W243. *(See Figure 3)*

A Catalog for Future Research

By creating a new database with more precise distances of the stars in Westerlund 1, further researchers will be able to utilize the new stellar models for understanding a variety of different topics, including stellar evolution of late-stage supermassive stars. The public database will serve as a critical resource for researchers as they study rare, supermassive-late stage stars such as the magnetar CXO J164710.20-455217 and the large variable blue star W243.

Data on these late-stage, supermassive stars will help *decipher the history* of the Westerlund 1 cluster – not only its age, but the process of formation from the hypothesized single-star burst formation. This will *further* the mission of Gaia to understand the structure and evolution of the Milky Way.

Figures

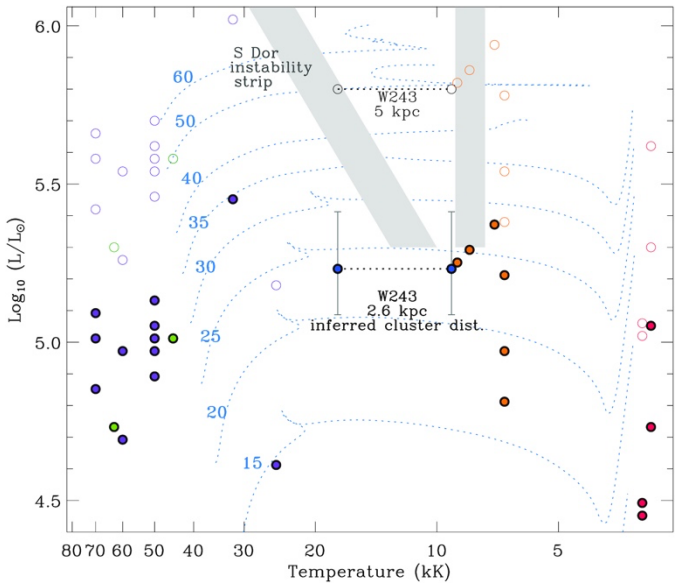

Figure 1: The HR Diagram for the stars in Westerlund 1. Open circles showcase the luminosities for stars prior to the DR2 release; the filled circles show the updated luminosities for the stars, ***showcasing the increased accuracy*** *in observations for this cluster, and highlighting the need for* ***further research****. (Aghakhanloo et. al, 2019)*

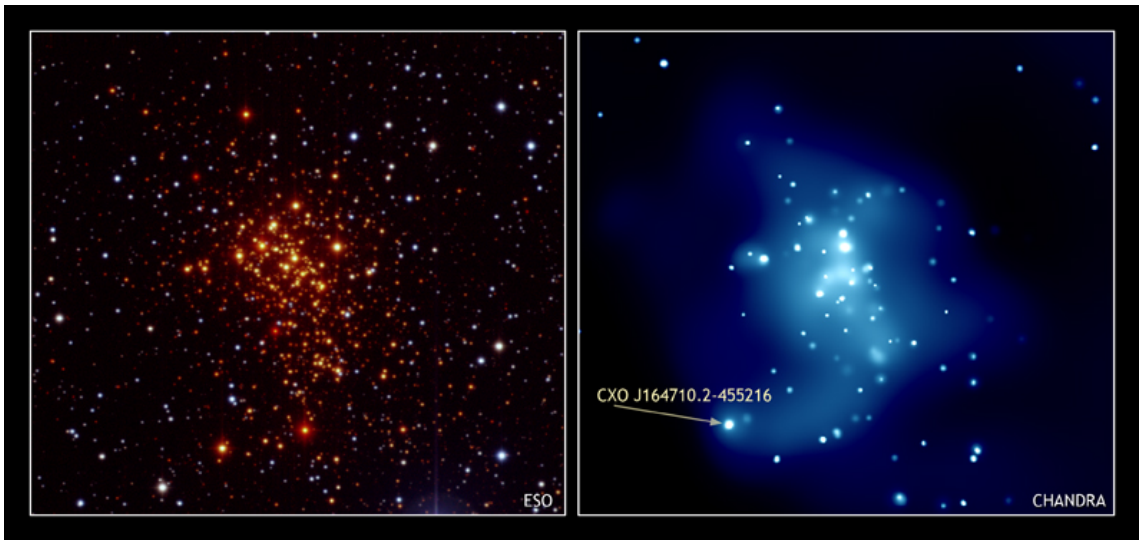

Figure 2: Westerlund 1 (left) is shown in visible light with the stars appearing red due to interstellar absorption; image on the right shows Westerlund 1 in the x-ray wavelength, highlighting the magnetar; ***understanding this star could help change further research on stellar evolution****. (Credit: NASA/CXC/UCLA/M.Muno et al.)*

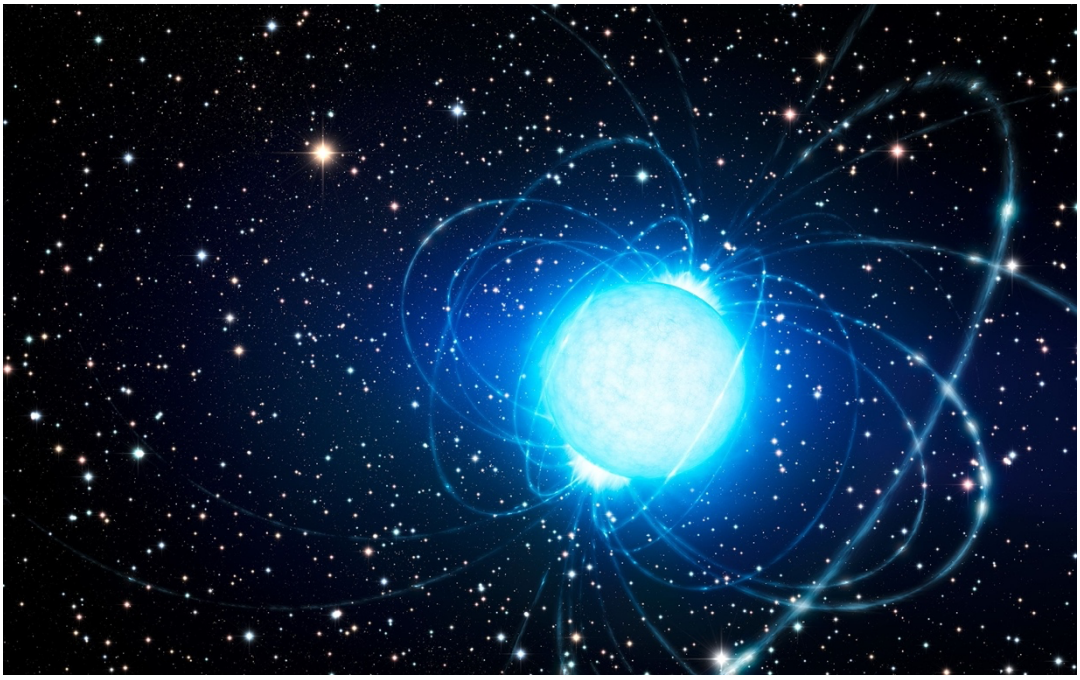

Figure 3: An artist's rendition of the magnetar located in Westerlund 1; understanding this magnetar is imperative in understanding the formation of the cluster. Image credit: ESO/L. Calçada.

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