CENTRAL UNIVERSITY OF KARNATAKA
DEPARTMENT OF PHYSICS

CROSS-CORRELATION OF X-RAY AND OPTICAL DATA OF GLOBULAR CLUSTERS USING VO SERVICES

In partial fulfillment for the requirements of the degree of Master of Science in Physics.

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DECLARATION

This project work was done by Navaneeth P K bearing registration no. 2018MPH20 from Department of Physics, Central University of Karnataka under my guidance at Department of Astronomy and Astrophysics, Tata Institute of Fundamental Research, Mumbai from 18-December-2019 to 18-March-2020.

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ABSTRACT

The Virtual Observatory provides an unified framework which enables transparent access to astronomical science data holdings coming from various different archives. All of the VO services are checked and installed in a datahub for data analysis. Globular clusters constitute fossil tracers of the dynamical and chemical evolution of the parent galaxy and Universe. Cross-matching astronomical catalogs is a central operation in astronomical data integration and analysis. X-ray and Optical data of two globular clusters 47 Tucanae and Terzan 5 is Cross-matched using VO services. Chandra and Gaia Obervatory data is used for data analysis. I've listed all x-ray sources matched with optical data. The 20 sources in 47 Tucanae and 35 sources in Terzan 5 are cross-correlated in position and verified that they belong to the respective globular clusters by comparing individual source distance with cluster distance. This will be the first accurate positional data of optical counterparts x-ray sources of 47 Tucanae and Terzan 5.

Keywords : Virtual Observatory, Globular cluster, Cross-match, Chandra, Gaia.

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Chapter 1

INTRODUCTION

1.1 Virtual Observatory

A virtual observatory (VO) is a collection of interoperating data archives and software tools which utilize the internet to form a scientific research environment in which astronomical research programs can be conducted. The VO consists of a collection of data centres each with unique collections of astronomical data, software systems and processing capabilities. The main goal is to allow transparent and distributed access to data available worldwide. This allows scientists to discover, access, analyze, and combine nature and lab data from heterogeneous data collections in a user-friendly manner. The IVOA (International Virtual Observatory Alliance) is a standards body created by the VO projects to develop and agree the vital interoperability standards upon which the VO implementations are constructed. The VO allows astronomers to interrogate multiple data centers in a seamless and transparent way, provides new powerful analysis and visualization tools within that system, and gives data centers a standard framework for publishing and delivering services using their data. This is made possible by standardization of data and metadata, by standardization of data exchange methods, and by the use of a registry, which lists available services and what can be done with them.

VO services are expected to return standard data formats, so that tools can make sensible use of the data. Generally this means industry standard formats such as JPG, or well known astronomical formats such as FITS and specialised VO format for tables of information, known as VOTable. All VO tools know how to deal with VO Tables, so you don't need to understand the structure, but the main advantage is that VOTable has more flexible descriptive metadata than for example CSV files or FITS tables. The VO aims at making it easy to access data over the internet, but it also aims at making tools in the VO club inter-operate with each other. The Astronomical Data Query Language (ADQL) is a proposed standard query language for the interoperability of the International Virtual Observatory. The data servers in the International Virtual Observatory could be searched using an ADQL query. The servers would return VOTables as a result of the query.

Cone search services offer the simplest access to astronomical catalogues. The input is sky-position and radius. The return is a subset of the catalogue within that radius. Table Access Protocol (TAP) services offer more flexible access to data tables, along the lines astronomers have become used to in making queries to databases like those of SDSS or UKIDSS. The input is a query in Astronomical Data Query Language (ADQL), which is basically a standardised version of SQL. The return is a data table. You don't necessarily have to learn ADQL, if for example the tool you are using can show you a list of the columns for that database, and give you an interactive way of building a query. Simple Image Access Protocol (SIAP) services offer access to pixel data. The input is a position and a size. If the SIAP service is a ”cut-out” service, the return will be an image centred at the requested position, with the requested size. If it is an ”Atlas” service, which holds a collection of standard sized data frames, then the size is used to look for frames centred within that distance of the requested position, and the whole data frame(s) returned. Simple Spectral Access Protocol (SSAP) services provide access to spectra. The input is a position and size. Like the ”atlas” version of image access, the return will be any spectra whose target positions are within the stated distance of the requested position. Registry Searching As discussed above, services put all sorts of useful information in their registry entries, and some tools make use of this. So for example, you can look specifically for image services, for X-ray data, for data curated by HEASARC, for services that are new this month, and so on.

1.2 Big data in Astronomy

Astronomy has been acquiring, systemizing and interpreting large quantities of data for ages. Like many other fields, astronomy has become a very data- rich field, supported by the advances in telescope, computer technology and detector. There already exist number of large sky surveys and archives, containing Terabytes and even larger amounts of information. The primary source of astronomical data is the observations of the sky in a systematic manner ranging over a high scope of wavelengths. Significant volumes of information are also being produced by number of simulations. Data mining has ensured the effectiveness and completeness of scientific utilization of these data, which has led to new area of astronomical research. Obtaining statistical descriptive data of our galaxy and the large-scale structure of the universe, to the discoveries of uncommon, unusual or even completely new types of celestial objects, a quantitively and qualitatively new science has been emerged due to astronomy. This new Big data related astronomy will provide ability to support scientists and students to engage in data rich astronomy without access to large telescopes. This will enlighten the field, as it allows access to fascinating amount of data to a fresh collection of talent.

The Virtual Observatory (VO) is a collective term which explains an ecosystem of standards and the organizations and tools which use those standards. The United States Astronomical Observatory is the infrastructure of software and development which lead to the establishment of the concept of operational Virtual observatory. VO is a concept that allows an astronomer to discover, access and process data without any boundaries regardless of its location physically. Several international efforts are currently funded in order to design and initiate the deployment of virtual observatories.

1.3 Globular Cluster

Stars are formed in gaseous clouds. When stars formed in a cloud there will be a tendency for a large number of them to be close together and hence they form star clusters. Clusters are divided into two broad categories known as open cluster and globular cluster. Open clusters are made up of population I stars. These clusters are found in galactic disk. They are relatively young objects. Some observations suggests that formation of open clusters is an ongoing process. These clusters are small in size. They contain 10^2 to 10^3 stars in a region of size 1 to 10 pc. There are 10^5 open clusters in milky way. Since these clusters are found in galactic disk, it is hard to identify them. A globular cluster is a spherical collection of stars that orbits a galactic core. They are very tightly bound by gravity, which gives them their spherical shapes, and relatively high stellar densities toward their centers. Globular clusters are the oldest in milky way , their chemical properties are almost similar and they are found in the halo of a galaxy. Gobular clusters contain some of the first stars to be produced in the galaxy, their origins and their role in galactic evolution are still unclear. A total of 152 globular clusters have now been discovered in the Milky Way galaxy, out of an estimated total of 180 20. These undiscovered globular clusters are believed to be hidden behind the gas and dust of the Milky Way. Radial velocity measurements have shown that most of the GCs are orbiting the Galaxy in highly eccentric elliptical orbits with orbital periods of about 10^8 yr or longer. The gobular clusters are made up of population II stars. A typical globular cluster contain 10^4 to 10^6 stars within a median radius of 10 pc. There age is around $10^1 0$ years.

The formation of globular clusters remains a poorly understood phenomenon and it remains uncertain whether the stars in a globular cluster form in a single generation or multiple generations over a period of several hundred million years. In many globular clusters, most of the stars are at approximately the same stage in stellar evolution, suggesting that they formed at about the same time. However, the star formation history varies from cluster to cluster, with some clusters showing distinct populations of stars. Globular clusters are generally composed of hundreds of thousands of low-metal, old stars. The type of stars found in a globular cluster are similar to those in the bulge of a spiral galaxy but confined to a volume of only a few million cubic parsecs. They are free of gas and dust and it is presumed that all of the gas and dust was long ago either turned into stars or blown out of the cluster during the initial burst of star formation. Globular clusters can contain a high density of stars.

In measuring the luminosity curve of a given globular cluster as a function of distance from the core, most clusters in the Milky Way increase steadily in luminosity as this distance decreases, up to a certain distance from the core, then the luminosity levels off. Typically this distance is about 1–2 parsecs from the core. However about 20% of the globular clusters have undergone a process termed ”core collapse”. In this type of cluster, the luminosity continues to increase steadily all the way to the core region. Core-collapse is thought to occur when the more massive stars in a globular cluster encounter their less massive companions. Over time, dynamic processes cause individual stars to migrate from the center of the cluster to the outside. This results in a net loss of kinetic energy from the core region, leading the remaining stars grouped in the core region to occupy a more compact volume. When this gravothermal instability occurs, the central region of the cluster becomes densely crowded with stars and the surface brightness of the cluster forms a power-law cusp. Over a lengthy period of time this leads to a concentration of massive stars near the core, a phenomenon called mass segregation. The different stages of core-collapse may be divided into three phases. During a globular cluster’s adolescence, the process of core-collapse begins with stars near the core. However, the interactions between binary star systems prevents further collapse as the cluster approaches middle age. Finally, the central binaries are either disrupted or ejected, resulting in a tighter concentration at the core.

1.3.1 Color-magnitude diagram

The Hertzsprung-Russell diagram (HR-diagram) is a graph of a large sample of stars that plots their visual absolute magnitude against their color index. The color index, BV, is the difference between the magnitude of the star in blue light, or B, and the magnitude in visual light (green-yellow), or V. Large positive values indicate a red star with a cool surface temperature, while negative values imply a blue star with a hotter surface. In HR diagram it is seen that the majority of stars lie in a single strip along the diagram, known as the main sequence, where in the brightest stars are the bluest, while the faintest stars are the reddest. Most of the stars occupy the region in the diagram along the line called the main sequence. During the stage of their lives in which stars are found on the main sequence line, they are fusing hydrogen in their cores. As all the stars of a globular cluster are at approximately the same distance from the Earth, their absolute magnitudes differ from their visual magnitude by about the same amount. The main-sequence stars in the globular cluster will fall along a line that is believed to be comparable to similar stars in the solar neighborhood. The accuracy of this assumption is confirmed by comparable results obtained by comparing the magnitudes of nearby short-period variables, such as RR Lyrae stars and cepheid variables, with those in the cluster. By matching up these curves on the HR diagram the absolute magnitude of main-sequence stars in the cluster can also be determined. This in turn provides a distance estimate to the cluster, based on the visual magnitude of the stars. The difference between the relative and absolute magnitude, the distance modulus, yields this estimate of the distance.

When the stars of a particular globular cluster are plotted on an HR diagram, in many cases nearly all of the stars fall upon a relatively well-defined curve. The shape of the curve for a globular cluster is characteristic of a grouping of stars that were formed at approximately the same time and from the same materials, differing only in their initial mass. As the position of each star in the HR diagram varies with age, the shape of the curve for a globular cluster can be used to measure the overall age of the star population. The most massive main-sequence stars will also have the highest absolute magnitude, and these will be the first to evolve into the giant star stage. As the cluster ages, stars of successively lower masses will also enter the giant star stage. Thus the age of a single population cluster can be measured by looking for the stars that are just beginning to enter the giant star stage. This forms a ”knee” in the HR diagram, bending to the upper right from the main-sequence line. The absolute magnitude at this bend is directly a function of the age of globular cluster, so an age scale can be plotted on an axis parallel to the magnitude. In globular clusters a few stars known as blue stragglers are observed, apparently continuing the main sequence in the direction of brighter, bluer stars. The origins of these stars is still unclear, but most models suggest that these stars are the result of mass transfer in multiple star systems.

1.3.2 Importance of Globular Cluster

Globular Clusters constitute fossil tracers of the dynamical and chemical evolution of the parent galaxy and can be used as test particles to evaluate both the galaxy's total mass and its radial distribution. GCs contain a variety of exciting objects by themselves worth a continuous investigation, for instance strong and weak x-ray sources, neutron stars and millisecond pulsars, white dwarfs, cataclysmic variables, binaries, blue stragglers, planetary nebulae, etc. Moreover, they contain one of the most popular intrinsic variable stars, the so-called RR LYRAE STARS . These stars have light variation amplitudes less than a couple of magnitudes and periods ranging from 0.2 to 1.1 days. Since their mean absolute magnitude is constant and fairly independent of metallicity (to within 0.3 mag), the RR Lyrae variables and the Gcs, in turn, are ideal standard candles to measure distances. Perhaps one of the most remarkable impacts of GC reasearch on other fields of astronomy is provided by the estimate of the ages of the Milky Way's globulars. Gcs are, in fact, among the few objects in the Galaxy for which relatively precise ages can be derived. Since they are the oldest objects observed in the Milky Way so far, and were born during the very early stages of the Galaxy's formation, they provide a very stringent lower limit to the age of the universe. Their age distribution and how ages vary with varying metallicity,spatial location in the Galaxy and kinematic properties make these systems direct tracers of the chronology of the first epoch of star formation in the Galactic halo and may help in understanding the whole process of galaxy formation.

Chapter 2

MULTIWAVELENGTH STUDY

2.1 Chandra X-ray Observatory

The Chandra X-ray Observatory is a Flagship-class space telescope by NASA on July 23, 1999. Chandra is sensitive to X-ray sources 100 times fainter than any previous X-ray telescope, enabled by the high angular resolution of its mirrors. Since the Earth's atmosphere absorbs the vast majority of X-rays, they are not detectable from Earth-based telescopes, therefore space-based telescopes are required to make these observations. Chandra is an Earth satellite in a 64-hour orbit, and its mission is ongoing as of 2020. The Chandra X-ray Observatory is part of NASA's fleet of "Great Observatories" along with the Hubble Space Telescope, the Spitzer Space Telescope and the now deorbited Compton Gamma Ray Observatory. The telescope specially designed to detect X-ray emission from very hot regions of the Universe such as exploded stars, clusters of galaxies, and matter around black holes. The Smithsonian's Astrophysical Observatory in Cambridge, MA, hosts the Chandra X-ray Center which operates the satellite, processes the data, and distributes it to scientists around the world for analysis.

The SIM (Science Instrument Module) consists of the special hardware that provides mechanical and thermal interfaces to the focal-plane scientific instruments (SIs). The most critical functions from an observer's viewpoint are the capability to adjust the telescope focal length and the ability to move the instruments along an axis orthogonal to the optical axis. The SIM houses the two focal instruments - the ACIS(Advanced CCD Imaging Spectrometer) and the HRC(High Resolution Camera). Each of these have two principal components — HRC-I and -S and ACIS-I and -S. ACIS consists of 10 CCD chips and provides images as well as spectral information of the object observed. It operates in the photon energy range of 0.2–10 keV. ACIS is an X-ray imager. X-ray photons hitting the camera are detected individually and their position, energy and arrival time recorded. This allows for high resolution (1 arcsec) imaging, moderate resolution spectroscopy and timing studies. ACIS can also be used with the HETG (High Energy Transmission Grating), and less commonly the LETG (Low Energy Transmission Grating) for high resolution spectroscopy. ACIS offers the capability to simultaneously acquire high-resolution images and moderate resolution spectra. The instrument can also be used in conjunction with the HETG or LETG to obtain higher resolution spectra. ACIS contains 10 planar, 1024 x 1024 pixel CCDs, four arranged in a 22 array (ACIS-I) used for imaging, and six arranged in a 16 array (ACIS-S) used either for imaging or for a grating spectrum read-out. Two CCDs are back-illuminated (BI) and eight are front-illuminated (FI). The response of the BI devices extends to energies below that accessible to the FI chips. The chip-average energy resolution of the BI devices is better than that of the FI devices. The HRC is comprised of two microchannel plate (MCP) imaging detectors: the HRC-I designed for wide-field imaging; and, HRC-S designed to serve as a read-out for the LETG. The HRC-I is placed at right angles to the optical axis, tangent to the focal surface. The HRC-S is made of three flat elements, the outer two of which are tilted to approximate the LETG Rowland circle. The HRC detectors have the highest spatial resolution on Chandra, matching the HRMA point spread function most closely. HRC has two micro channel plate components and images over the range of 0.1–10 keV. It also has a time resolution of 16 microseconds. The transmission gratings, which swing into the optical path behind the mirrors, provide Chandra with high resolution spectroscopy. The High Energy Transmission Grating Spectrometer (HETGS) works over 0.4–10 keV and has a spectral resolution of 60–1000. The Low Energy Transmission Grating Spectrometer (LETGS) has a range of 0.09–3 keV and a resolution of 40–2000. Chandra carries four very sensitive mirrors nested inside each other. The energetic X-rays strike the insides of the hollow shells and are focussed onto electronic detectors at the end of the 9.2- m (30-ft.) optical bench. Depending on which detector is used, very detailed images or spectra of the cosmic source can be made and analyzed.

Chandra allows scientists from around the world to obtain X-ray images of exotic environments to help understand the structure and evolution of the universe. The CXO, which was launched by Space Shuttle Columbia in 1999, can better define the hot, turbulent regions of space. This increased clarity can help scientists answer fundamental questions about the origin, evolution, and destiny of the universe.

2.2 Gaia

GAIA builds upon the observational techniques pioneered and proven by ESA's Hipparcos mission to solve one of the most difficult yet deeply fundamental challenges in modern astronomy – to create an extraordinarily precise three-dimensional map of our Galaxy and beyond. In the process, by combining positional data with radial velocities, GAIA will map the stellar motions, which encode the origin and subsequent evolution of the Galaxy. Through comprehensive photometric classification, GAIA will provide the detailed physical properties of each star observed, characterising their luminosity, temperature, gravity and elemental composition. This massive multi-parameter stellar census will provide the basic observational data required to quantify the origin, structure and evolutionary history of our Galaxy. The primary science goal of the GAIA mission is to clarify the origin and history of our Galaxy, quantifying tests of galaxy formation theories, and also dramatically advancing our knowledge of star formation and evolution. This is possible since low-mass stars live for much longer than the present age of the Universe, and retain in their atmospheres a fossil record of the chemical elements in the interstellar medium at the time of their formation. The orbits of these stars similarly encode their dynamical histories, so that the GAIA results will precisely identify relics of tidally-disrupted accretion debris, and probe the distribution of dark matter. The GAIA survey will establish the luminosity function for pre-Main Sequence stars, detect and categorise rapid evolutionary stellar phases, place unprecedented constraints on the age, internal structure and evolution of all stellar types, establish a rigorous distance-scale framework throughout the Galaxy and beyond, and classify the star formation, kinematical and dynamical behaviour across the Local Group of galaxies.

GAIA will provide distances of astonishing accuracy and in remarkable numbers for all types of stars of all stellar populations, even the brightest, or those in the most rapid evolutionary phases, which are very sparsely represented in the solar neighbourhood. About 20 million stars will be measured with a distance precision of 1% (compared to a few hundred now), and about 200 million will be measured to better than 10% (compared to about 20 000 now). Some 10 million resolved binary systems will be detected within 250 pc. With the parallel determination of extinction/reddening and metallicities by the use of multi-band photometry and spectroscopy, this huge amount of basic data will provide an extended basis for reading in-situ stellar and galactic evolution. All parts of the Hertzsprung-Russell diagram will be comprehensively calibrated, including all phases of stellar evolution, from pre-Main Sequence stars to white dwarfs and all existing transient phases; all possible masses, from brown dwarfs to the most massive O stars; all types of variable stars; all possible types of binary systems down to brown dwarf and planetary systems; all standard distance indicators (pulsating stars, cluster sequences, supergiants, central stars of planetary nebulae, etc.). This extensive amount of data of extreme accuracy will stimulate a revolution in the exploration of stellar and galactic formation and evolution, and the determination of the cosmic distance scale. GAIA photometric measurements will provide essential diagnostic data, allowing the classification of all objects observed on the basis of luminosity, effective temperature, mass, age and composition. GAIA addresses science of enormous general appeal, and will deliver huge scientific impacts across the whole of astrophysics from studies of the Solar System, and other planetary systems, through stellar astrophysics, to its primary goal, the origin and evolution of galaxies, out to the large-scale structure of the Universe, and fundamental physics.

The Gaia objective is to provide a very accurate dynamical 3D map of our Galaxy by using global astrometry from space, complemented with multi-color multi-epoch photometric measurements. The aim is to produce a catalog complete for star magnitudes up to 20, which corresponds to more than one billion stars or about 1% of the stars of our Galaxy. The instrument sensitivity is such that distances beyond 20-100 kiloparsec (kpc) will be covered, therefore including the Galaxy bulge (8.5 kpc) and spiral arms. The measurements will not be limited to the Milky Way stars. These include the structure, dynamics and stellar population of the Magellanic Clouds, the space motions of Local Group Galaxies and studies of supernovae, galactic nuclei and quasars, the latter being used for materializing the inertial frame for Gaia measurements.

2.2.1 Gaia's Virtual Observatory

ESA's Gaia mission will survey the sky for at least 5 years providing high accuracy astrometry, radial velocities and multi-color photometry. The DPAC (Data Analysis and Processing Consortium) efforts will result in an astronomical catalog with unprecedented accuracy and completeness of at least 1 billion (109) sources, and over 1PB of associated data products. This brings big data challenges in storing, querying and distributing all the associated data and meta data, comparing them with other astronomical catalogues, enabling analysis, visualization, data mining and then sharing these results with other scientists. The amount of data involved forces a change of paradigm in dealing with astronomy archives. The Gaia archive will provide an infrastructure to run added value interfaces and software on top of the Gaia data.

Chapter 3

DATA ANALYSIS

The globular clusters are very efficient catalysts in forming unusual astronomical sources, such as low-mass X-ray binaries (LMXBs), cataclysmic variables (CVs), and millisecond pulsars (MSPs). The high stellar densities in globular clusters trigger various dynamical interactions: exchange encounters, direct collisions, destruction of binaries, and tidal capture.

3.1 Installation of VO Services

All Virtual Observatory services are studied and checked. Tried to Install all of the softwares into a datahub before data analysis. A table is made by listing all VO services and their relevent informations. The status of VO services installation in the datahub is given below.

Table 3.1: VO services installation data

Number of Virtual Observatories	21
Number of Services	66
Software Services	41
Web Services	25
Other softwares	13
Installed in the datahub	26
Issues with installation	15
Prerequisites installed	5

3.2 47 Tucanae

47 Tucanae, (47 Tuc or NGC 104) is a globular cluster located in the constellation Tucana. It is about 4.0 0.35 kpc away from Earth, and 120 light years across. 47 Tucanae is the second brightest globular cluster after Omega Centauri and the cluster may contain an intermediate-mass black hole. 47 Tucanae contains hundreds of X-ray sources, including stars with enhanced chromospheric activity due to their presence in binary star systems, cataclysmic variable stars containing white dwarfs accreting from

companion stars, and low-mass X-ray binaries containing neutron stars that are not currently accreting, but can be observed by the X-rays emitted from the hot surface of the neutron star. 47 Tucanae has 25 known millisecond pulsars, the second largest population of pulsars in any globular cluster. It is not yet clear whether 47 Tucanae hosts a central black hole. The cluster's Hertzsprung–Russell diagram suggests stars approximately 13 billion years old.

Figure 3.1: NASA Skyview Image of 47 Tucanae

Table 3.2: Data sheet of 47 Tucanae

Name	47 Tucanae
Object Type	Globular Cluster
Constellation	Tucana
Distance	4.0 +- 0.35 kpc
Apparent Magnitude	+4.5
RA (J2000)	00h 24m 05s
DEC (J2000)	-72d 04m 51s
Age	13.1 Gyr
Mass	7 x 10^5 Solar mass

3.3 Terzan 5

Terzan 5 is a heavily obscured globular cluster belonging to the bulge of the Milky Way galaxy. It is situated in the Sagittarius constellation in the direction of the Milky Way's center. Terzan 5 probably follows an unknown complicated orbit around the center of the galaxy. Terzan 5 consists of at least two generations of stars with ages of 12 and 4.5 billion years and slightly different metallicities, possibly indicating that it is the core of a disrupted dwarf galaxy, not a true globular cluster. Terzan 5 is known to contain at least 34 millisecond radio pulsars. The large number of X-ray sources and millisecond pulsars may be a direct consequence of the high density of the cluster's core, which leads to a high rate of star collisions, and to formation of close binaries, including binary systems which contain a neutron star. The properties of Terzan 5 are uncommon for a globular cluster, they are very similar to the stellar population which can be found in the galactic bulge, the tightly packed central region of the Milky Way. These similarities could make Terzan 5 a fossilised relic of galaxy formation, representing one of the earliest building blocks of the Milky Way.

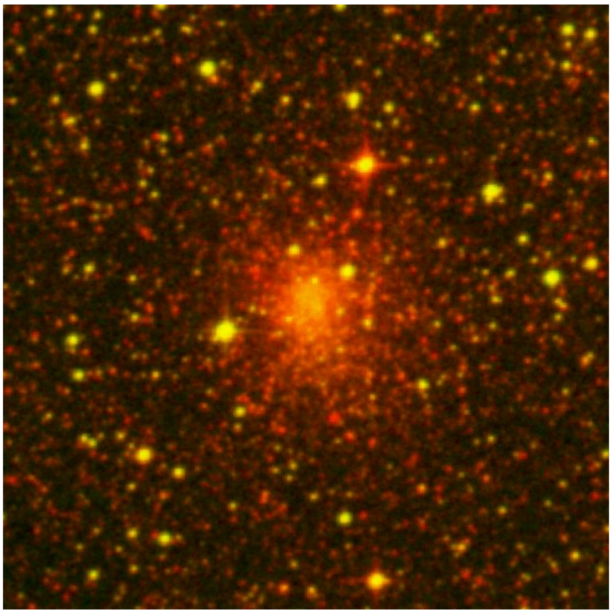

Figure 3.2: NASA Skyview Image of Terzan 5

Table 3.3: Data sheet of Terzan 5

Name	Terzan 5
Object Type	Globular Cluster
Constellation	Sagittarius
Distance	5.9 +- 0.5 kpc
Apparent Magnitude	+12.8
RA (J2000)	17h 48m 05s
DEC (J2000)	-24d 46m 48s
Age	12 Gyr
Mass	2 x 10^6 Solar mass

3.4 Positional cross-match

Positional cross-match is a join of two catalogs based on the proximity of their objects' coordinates: in the simplest case, a row in table A will be joined to (potentially k) nearest neighbors in table B. More usefully, the cross-match is made probabilistically, taking measurement errors and other uncertainties into account. Cross-matching is the fundamental operation in survey data analysis. It makes it possible to associate and gather data about the same physical phenomenon (object) observed in different catalogs (wavelength regimes and timescales) or at different times within the same catalog. It allows one to query the neighborhood of the objects. Such joined and integrated information can then be fed to higher-level functions to infer the nature of the object, predict its expected behavior, and potentially assess its importance as a followup target.

3.4.1 CDS Xmatch Service

The CDS cross-match service is a new tool allowing astronomers to efficiently cross-identify sources between very large catalogues (up to 1 billion rows) or between a user-uploaded list of positions and a large catalogue. Users interact with the CDS xMatch service through a Web application which should run fine on any recent Web browser having Javascript and cookies enable. One can upload your own table in one of the following formats : VOTable, FITS table or CSV (Comma separated values) table.

3.4.2 Chandra Positional Accuracy

The absolute positional accuracy of source coordinates in Chandra observations is based on measuring the distances between the Chandra X-ray source positions and corresponding optical/radio counterpart positions from two accurate catalogs (Tycho2 or ICRS). The overall 90% uncertainty circle of Chandra X-ray absolute position has a radius of 0.8 arcsec. The 99% limit on positional accuracy is 1.4 arcsec. The worst case offset is 2.0 arcsec. Performance varies slightly between detectors.

Chapter 4

RESULTS AND CONCLUSION

The positional cross-match between two catalogues are done by the CDS Xmatch service. The local table of Chandra sources are cross-matched with Gaia DR2 and Gaia DR2 distances (Bailer-Jones et al. 2018) catalogues from CDS Xmatch. X- ray sources are taken from CSC 2.0 (Chandra Source Catalog). The result of the positional cross-match for the two globular clusters are given below.

Table 4.1: Cross-match result

	47 Tucanae	Terzan 5
Number of x-ray sources	479	276
Chandra X Gaia DR2 sources	94	152
Chandra X Gaia DR2 sourcesmissing parallax	32	54
Chandra X Gaia Distance sources	57	97
Chandra X Gaia Distances sources with distance matching to cluster distance	20	35

Table Metadata :

d_arcsec : Angular distance (in arcsec)
$name$: Chandra source id
ra : Right Ascension (in degree)
dec : Declination (in degree)
$rest$: Estimated distance (in parsec)
b_rest : The linear distance in minimum or lower limit. (in pc)
B_rest : The linear distance in maximum or Upper limit. (in pc)

Table 1: **47 Tucanae - Chandra and Gaia distance crossmatch result**
Number of Sources matched = 20

d_arcsec	name	ra	dec	rest	b_rest	B_rest
0.097337	2CXO J002413.7-720334	6.057498901022768	-72.0595751889461	3749.83232967753	2741.24698049575	5114.28728624164
0.152218	2CXO J002431.8-720929	6.1326291852672625	-72.15819866141501	3252.282545066	2734.19824779474	3960.62992134442
0.180046	2CXO J002414.5-720653	6.06057851931098	-72.11490735808984	3612.09168029817	3094.32573767512	4298.07748759027
0.190346	2CXO J002330.7-722043	5.878169734633218	-72.34542654362319	3321.97985782066	2498.94995430482	4499.73309986393
0.200491	2CXO J002407.7-720431	6.032338072629955	-72.07538061513691	3214.69768119327	2683.32177258659	3947.90652088542
0.231102	2CXO J002402.0-720133	6.008611501884616	-72.02595570199736	2798.83059882521	1953.81576081159	4024.94425167105
0.268318	2CXO J002442.5-715923	6.177198142474197	-71.98985687107627	5307.18534357241	4545.4343027936	6290.52578293453
0.383733	2CXO J002424.2-720744	6.101112951006883	-72.12903496842927	3525.97295594683	2597.25534190969	4811.67726948786
0.410914	2CXO J002240.9-720922	5.670419236549037	-72.15614646657401	3672.11069327876	3129.21278208324	4395.62926270156
0.421547	2CXO J002336.2-720403	5.901094048933373	-72.0676754100641	3510.69333535451	2525.46599929013	4854.61122592673
0.425485	2CXO J002437.1-720516	6.154885719826211	-72.08802075077033	5692.60054107739	4499.91332462189	7217.14332329624
0.531219	2CXO J002357.5-720753	5.989810098408498	-72.1315089290702	3616.06166689322	2818.30361821636	4740.85242504125
0.592097	2CXO J002408.3-720435	6.034675421732686	-72.07661778720566	4966.97421631205	4225.33297357271	5936.83324396924
0.632859	2CXO J002408.3-720431	6.034720257866809	-72.07541651218435	3206.13074043151	2602.90534135814	4061.32230262166
0.645222	2CXO J002352.2-720723	5.9677763248395195	-72.1232571626284	2991.2991281475	2108.05707896553	4253.09494864157
0.690982	2CXO J002339.5-720140	5.914804828760566	-72.02794048261217	4026.75451442225	3099.85534032554	5294.40945001768
0.856889	2CXO J002413.8-720302	6.057576036864248	-72.05062956003316	3886.99515890482	3148.56723222813	4907.48614169392
0.875722	2CXO J002339.7-715846	5.915696962468189	-71.97967377827386	3108.46028883578	2355.11729060737	4202.52168869431
0.938062	2CXO J002549.9-720220	6.458087028647412	-72.0389697500212	4721.30694558962	3622.03294163545	6167.05804297896
0.969678	2CXO J002446.8-721235	6.195294441806084	-72.20975528213975	2712.3333992075	1976.89317470969	3818.96282511654

Table 2: **Terzan 5 - Chandra and Gaia Distance Crossmatch result**
Number of Sources matched = 35

d_arcsec	name	ra	dec	rest	b_rest	B_rest
0.043683	2CXO J174821.0-244622	267.0877583893497	-24.772922522936287	6386.68478165958	3949.04742733012	10212.1513270264
0.067491	2CXO J174818.1-244759	267.0757077657835	-24.799891185038216	6004.6108106318	3834.82491351362	9611.95185775287
0.111292	2CXO J174817.4-244521	267.072525658441	-24.755871973929736	898.845210944329	448.032265530029	5369.4487322343
0.146641	2CXO J174815.5-244424	267.0647506931982	-24.740204355712773	2006.48827174363	866.104215136196	5782.93242225861
0.152797	2CXO J174759.7-244529	266.99908790602126	-24.758226805277534	4928.13456322015	2679.41294138238	8664.22533745524
0.180642	2CXO J174801.5-244621	267.0062560250352	-24.772691411084327	5407.26674580298	3233.85889261196	9084.93503523707
0.200655	2CXO J174749.7-244628	266.9574110081676	-24.77456164141194	4695.27292233854	2530.74062976363	8383.78064566909
0.205602	2CXO J174805.7-244603	267.0241551778024	-24.76767872118955	1687.30532162338	862.56661421574	5240.20119667864
0.209802	2CXO J174808.5-245007	267.0356263625331	-24.83547874374441	799.057169612817	399.626916350014	5570.22260251171
0.210294	2CXO J174816.5-244544	267.06907095016186	-24.762465110304205	2533.4669671745	1069.23474261619	6211.82795694688
0.219794	2CXO J174804.6-244625	267.01933769653647	-24.77373187555472	5630.45445479302	3165.8576296355	9504.1003917149
0.226092	2CXO J174814.4-245247	267.0601010968013	-24.879930403712176	4570.07798659481	2380.1992455775	8289.57625185561
0.347095	2CXO J174809.5-245038	267.0399986655416	-24.84389373643613	2212.87573739462	1087.37664166338	5787.78148678588
0.367953	2CXO J174803.9-244647	267.0166253862842	-24.779865409081363	7376.37267188597	4633.32040768097	11451.1420706552
0.393103	2CXO J174804.4-244641	267.01836699084674	-24.778180208416092	8151.17798358079	5337.21680627733	12279.4338516893
0.398339	2CXO J174804.2-244642	267.01764202358197	-24.77846233134111	1676.53993743781	917.378551762493	4874.60052066994
0.45049	2CXO J174759.8-245113	266.99922029498407	-24.853887079127727	5119.71170038555	2913.43846427243	8864.40628870409
0.497128	2CXO J174811.7-245227	267.0490286536649	-24.874280049140474	4773.76707870783	2418.54907306685	8594.21922170177
0.50571	2CXO J174801.0-244603	267.0043435627124	-24.76753251486742	2717.27168977527	1225.19138001054	6373.1986557043
0.539631	2CXO J174805.2-244651	267.0219403133294	-24.78102734992217	5720.97684442662	3251.570368576	9597.32237571425
0.548905	2CXO J174809.9-245305	267.04137043547735	-24.884814110831464	2472.42409110678	1574.86760011126	4853.13598586336
0.55955	2CXO J174803.8-244646	267.0160442344579	-24.77950445290128	5936.07623773853	3460.65391201491	9813.38689574157
0.579317	2CXO J174803.8-244641	267.0160200947728	-24.778283942784316	1167.09575948485	625.643035658516	4660.73480008874
0.584312	2CXO J174804.8-244649	267.0200924450189	-24.780310665975488	5632.15947240131	3225.09558123611	9463.46290232199
0.748822	2CXO J174756.0-245042	266.9834845896646	-24.845017241449604	2815.94286916547	1647.64829655892	5870.94716130249
0.767842	2CXO J174755.8-244622	266.98259481556636	-24.77299890905729	5140.04626619331	2764.15975931248	8962.55355329714
0.796477	2CXO J174805.3-244631	267.02228554361113	-24.775515583896496	5533.24764074136	3150.61995389297	9347.91183995608
0.832177	2CXO J174804.6-244645	267.01921946716845	-24.77930247189263	4677.64352148733	2641.04607325009	8294.02605245206
0.850222	2CXO J174815.2-244259	267.0633529740346	-24.716417486157116	5326.04304128205	3036.40026249038	9066.6915161192
0.874882	2CXO J174806.1-244642	267.02580308636357	-24.778577383779357	5060.78330988002	2677.55191415126	8886.96787448747
0.887164	2CXO J174800.7-245021	267.0031513391134	-24.83931875969813	5585.97403461082	3349.93502675769	9318.09642405234
0.928007	2CXO J174808.8-244630	267.03681759023834	-24.77519824508425	2366.46268289717	433.234276194498	5994.6952156597
0.957839	2CXO J174806.0-244624	267.0253503894502	-24.77343728702797	5217.64181085523	2817.06820246265	9052.44380922599
0.959939	2CXO J174804.8-244645	267.02005186497126	-24.77918113725092	1036.93456157481	541.542692067459	4916.11068409163
0.969114	2CXO J174804.5-244642	267.0190356246562	-24.778377500146824	1756.60203067584	979.647826709271	4852.21021438839

The distance for the given clusters are 4.29 +- 0.47 kpc and 5.5 +- 0.9 kpc for 47 Tucanae and Terzan 5 respectively. I've listed all x-ray sources matching within the distance error range. These 20 sources in 47Tucanae and 35 sources in Terzan5 are cross-correlated in position and verified that they belong to the respective globular clusters by comparing individual source distance with cluster distance. This will be the first accurate positional data of optical counterparts x-ray sources of 47 Tucanae and Terzan 5.

Chapter 5

FUTURE WORK

The Python programming language has become one of the fastest growing programming languages in the astronomy community. While there have been a number of efforts to develop Python packages for astronomy specific functionality, these efforts have been fragmented, and several dozens of packages have been developed across the community. Astropy is a collection of software packages written in the Python programming language and designed for use in astronomy. The software is a single, free, core package for astronomical utilities due to the increasingly widespread usage of Python by astronomers, and to foster interoperability between various extant Python astronomy packages. astropy.coordinates subpackage contains classes and functions for celestial coordinates of astronomical objects. It also contains a framework for conversions between coordinate systems. The module contains commonly-used tools for comparing or matching coordinate objects. Importance of the module is to determining separations between coordinates and those for matching a coordinates to a catalog.

The future work is to make a python code that can find exact optical counter part of x-ray sources using AstroPy and its modules. The program will check all optical sources present in the chandra source error circle and find closest match. Then the closest matched source will be verified from its distance by comparing with cluster distance. In that way we can verify that the source belong to the respective globular cluster. From this python code, we can find exact optical counter part for the x-ray sources and verify current cross-match result from VO services.

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