

## ABSTRACT

The astrolabe collection of the Adler Planetarium and History of Astronomy Museum, Chicago, IL, was examined using non-destructive synchrotron based high-energy X-ray techniques including diffraction, fluorescence, and radiography to determine the metallurgy, microstructure, and metal forming processes used in astrolabe construction. All high-energy X-ray measurements were performed at the Advanced Photon Source (APS) synchrotron of Argonne National Laboratory, Argonne, IL. Astrolabes from the collection were selected to represent all major astrolabe production centers possible and time periods. It was found that all European astrolabes were manufactured of traditional cementation brass by hand worked metal forming processes consistent with technology in the literature. Of the Islamic astrolabes examined, all seven from Lahore in current-day Pakistan exhibited advanced brass alloys not typical of alloys discussed in the literature. It was found that these alloys were selected for their specific hot working properties, allowing the Lahore metalworkers to more efficiently make brass sheet from which to make astrolabe components. In addition, the alloy required a fundamental change in the brass foundry process, indicating advanced Zn metal production techniques.

It was found that analysis by high energy X-rays from the APS was essential to produce data on the chemistry and microstructure from the interior of the astrolabe components in a non-destructive manner. Many astrolabe components had undergone surface dezincification due to heavy annealing during manufacturing, causing the Zn composition measured by the surface sensitive fluorescence technique to be lower than

the true bulk alloy Zn composition. This would have been impossible to quantify non-destructively without the high-energy diffraction capability of the APS. The results of this study have proven the effectiveness of the synchrotron as a viable non-destructive analysis technique for examining cultural, historic, and archaeological materials. The unique characteristics of the synchrotron allow analysis techniques previously unavailable to the scientist.

## 1.0 Introduction

The astrolabe has often been called the first scientific instrument of the modern era. Created as a mechanical map of the Sun and star movements, the astrolabe was the most important astronomical tool in pre-telescopic astronomy. In addition it could be used to tell the time night or day from the position of the sun and stars, and was also a useful navigation and surveyor's tool. The instrument was invented by the Greeks around 100 B.C., rejuvenated by Muslim scientists interested in rediscovering Greek scientific work during the 9<sup>th</sup> century, and later transmitted to Christian Europe in the 11<sup>th</sup> century. The instrument was so important that Chaucer wrote the first technical document of the English language describing the astrolabe and its use [**Ovitt; Robinson**]. Later in the Renaissance, astrolabes were often symbolically used by artists to depict the arts or were often placed in portraits to illustrate the patron as a supporter of the pursuit of knowledge [**Turner, p.43**].

The instrument has its origins in the stereographic projection developed by Hipparchus of Nicea (150 B.C.) to accurately map the three dimensional arrangement of the stars in the sky on a two dimensional plane. The Greeks believed that the stars were situated on the Celestial Sphere, a great sphere at the center of which was the Earth. The stereographic projection allowed the three dimensional star positions to be mapped on a plane while retaining two key features for studying the stars: 1) circles on the celestial sphere were mapped as circles on the stereographic projection, and 2) the intersection angles of circles on the celestial sphere were the same when plotted on the stereographic projection [**North p. 101**].

Unfortunately no Greek astrolabes exist today; the earliest known astrolabes were manufactured in the 10<sup>th</sup> century [**Turner, p. 14; Michel**]. There was a great demand for astrolabes around the Islamic lands as they gave an accurate technique to determine both the time for prayer and the direction to Mecca. The spread of the astrolabe into Muslim Spain led to the transmission of the instrument across the Pyrenees to Christian Europe in the 11<sup>th</sup> century [**Turner, p. 16**]. The instrument was the pinnacle of scientific instruments until it was replaced by more specialized instruments during the mid 17<sup>th</sup> century in Europe; it held on until the mid 19<sup>th</sup> century in some Islamic lands.

Previous comprehensive studies of astrolabes have focused on the individual instrument makers or production centers as related to stylistic studies for authentication and the astronomy, not the metallurgical technology and metalworking skills required to produce astrolabes as a material object [**Van Cleempoel, Lamprey**]. The only studies in the literature of the metallurgy and metalworking technology used in astrolabe manufacture are by Gordon and were limited to two astrolabes by Georg Hartmann [**Gordon 1986, Gordon 1987**]. Gordon prepared metallurgical samples from the Hartmann astrolabe in the Yale University collection, and directly examined the microstructure of the brass. These studies are crucial in our understanding of astrolabe and medieval metallurgy and metal forming; however, the destructive analysis technique used is also the reason why only two astrolabes were studied and there have been no other metallographic studies since. Museums and private collectors

either outright forbid or are very hesitant to allow samples to be cut from astrolabes or *in situ* polishing and etching that is required for metallographic study.

The astrolabe was used for over 1000 years as the pinnacle of pre-telescopic astronomy in Christian and Muslim cultures. It represents the highest quality craftsmanship and is a perfect artifact with which to learn and compare the technology of metalworking techniques of these cultures. In this study of astrolabes, the final goal was to use completely non-destructive analysis techniques to understand the metallurgy and processes with which astrolabes were manufactured from many makers, time periods, and production centers of the Middle Ages. In the first chapter, a concise review of the history and construction of astrolabes is presented.