Observational Astrophysics
24. Astrometry

Rodolfo Smiljanic
Autumn/Winter 2021/2022

Nicolaus Copernicus Astronomical Center
Polish Academy of Sciences
ul. Bartycka 18
00-716 Warsaw, PL

E-mail: rsmiljanic@camk.edu.pl
Office: 115

http://users.camk.edu.pl/rsmiljanic

1 Introduction

Astrometry is the oldest branch of astronomy. Astrometry concerns itself with measuring the position in the sky of astronomical sources and, by extension, with the variation in time of those positions. With such measurements we can determine distances using parallax, motions in space using proper motions, orbits of binary stars, and predict the occultation of stars by solar system objects. Astrometry is also the area that produces the catalogues of positions that we need to find the objects that we want to observe.

The more accurate and precise are the astrometric measurements, the more amazing is the science that they enable. Tycho Brahe's observations of planets allowed Kepler to derive his laws of planetary motion. We are now at a time expecting that the astrometric data from the *Gaia* mission might reveal the precession of the spin axis of the Galactic plane (Perryman et al. 2014)[1]. An effect estimated to be of the order of 30μas per year...

2 Read these texts

About astrometry, please read Section 5.1 of the book "Astrophysical Techniques" by Kitchin (2020)[2]. The text provides a quick background on coordinates and then short descriptions of equipment and techniques that can be used for astrometric measurements.

And about the *Gaia* mission, please read Gaia Collaboration et al. (2016)[3].

3 Summary of concepts

- Small-field astrometry uses the image of a certain field to determine the relative positions of the objects that can be observed simultaneously. The straightforward imaging with CCDs can

[1] https://ui.adsabs.harvard.edu/abs/2014ApJ...789..166P/abstract

[2] https://www.google.com.br/books/edition/Astrophysical_Techniques_Sixth_Edition/fU3BAQAAQBAJ?hl=en&gbpv=0

[3] https://ui.adsabs.harvard.edu/abs/2016A%26A...595A...1G/abstract

be used for that. (Semi-)Global astrometry aims to connect the relative position of objects even if they are not observed in the same field. The term semi-global is used when only a part of the sky can be observed, as when using a meridian circle in a given observatory, while global refers to all-sky observations (as possible with *Gaia*).

- Transiting telescopes (or meridian circles) are used to observe an object at the moment it crosses the local meridian. The right ascension of the object is then the local sidereal time of the transit, and the declination can be obtained from the telescope altitude and the latitude of the location where the observations are made.

- Dedicated telescopes for obtaining images of the sky with the purpose of measuring positions of the objects are sometimes called "astrographs". Most of the early examples were refractors with a field of view of a few degrees. The name astrograph is reflected in the name of some catalogues, such as UCAC, the US Naval Observatory CCD Astrographic Catalog (Zacharias et al. 2013)[4].

- Schmidt telescopes have also been used to obtain images for astrometry. A Schmidt telescope is a design with a spherical primary mirror and an aspherical correcting lens, to eliminate spherical aberration and enable observations over a wide field of view. The image is formed inside the telescope, at the prime focus. The focal plane is curved, and the detector will need to follow that curvature (traditionally photographic plates), although a field flattener system (with lenses, for example, could also be used). The Hipparcos and Kepler missions had the Schmidt telescope design.

- One method used in CCD astrometric observations is the "drift-scan" or "time delay integration". The idea is to keep the telescope fixed (it does not track the object) and let the sources drift across the field of view. The detector is oriented parallel to the motion of the stars. The charge transfer of the CCD is performed continuously, matching the rate with which the sources drift. This helps with the stability of the telescope, as it is not moving, and can also enable linking the position of faint and bright sources existing in the same field. The method seems to have been introduced by Gehrels et al. (1986)[5].

- *Gaia* also performs the astrometric measurements by scanning, i.e. by letting the sources drift across the focal plane. In this case however, the spacecraft is not fixed, but is moving according to a scanning law. The basic principles are given in Lindegren & Bastian (2010)[6].

- We touched upon the idea of reference frames before. Such reference is needed to determine small apparent motions in a close to absolute way. Apart from a few exceptions (e.g. jets), extragalactic sources (quasars and distant galaxies) have positions that are fixed in the sky, to the precision with which we can make such measurements. Astrometric observations of such "fixed objects" are essential for the creation of such reference frames.

- One of the most important parameters obtained from astrometric measurements of stars is the "parallax". The annual parallax is the apparent displacement of a star on the celestial sphere because of the orbital motion of the Earth around the Sun. For an angular displacement (the parallax, ϖ) measured in arcseconds, the distance in parsecs is given by $d = 1/\varpi$, assuming that the uncertainty in ϖ is small.

[4] https://ui.adsabs.harvard.edu/abs/2013AJ....145...44Z/abstract

[5] https://ui.adsabs.harvard.edu/abs/1986AJ.....91.1242G/abstract

[6] https://www.researchgate.net/publication/253046396_Basic_principles_of_scanning_space_astrometry

- If the uncertainty in ϖ is not small, it is important to note that symmetric errors in ϖ do not translate into symmetric errors in distance. As a result, the most probable value of the distance is larger than $1/\varpi$.

- The proper motion (μ) is another parameter obtained from astrometric measurements of stars. The proper motion is the projection on the sky of the motion of a star with respect to the barycenter of the Solar System. This motion is usually decomposed in the equatorial coordinate system. The resulting proper motion components (μ_α and μ_δ) are usually expressed as yearly variations of the equatorial coordinates, right ascension (α) and declination (δ).

- Most catalogues will actually list μ_α^*, instead of μ_α, and call it anyway the proper motion in right ascension, where $\mu_\alpha^* = \mu_\alpha \cos\delta$. The "cos" factor appears in the trigonometric decomposition of the proper motion components. It is indeed μ_α^* that is usually required for other calculations of stellar motions.

- Interferometers, in the optical and radio, can also be used for astrometry, as the high spatial resolution means positions of high accuracy. Nevertheless, the field of view is small and only one or few sources will be observed at a time. The technique is interesting, anyway, for following the motion of stars in a binary system with high accuracy, for example.

4 Additional reading

For more details, have a look at the book "Modern Astrometry" by Kovalevsky (2002)[7]. Chapter 4, in particular, presents more details about the reduction of the observations to get the astrometric information out of the data. Chapters 9 and 10 discuss the use of interferometry in astrometry.

For a historical review of astrometry, from Tycho Brahe to the Hipparcos satellite, see Høg (2009)[8].

References

Gaia Collaboration, Prusti, T., de Bruijne, J. H. J., et al. 2016, A&A, 595, A1

Gehrels, T., Marsden, B. G., McMillan, R. S., & Scotti, J. V. 1986, AJ, 91, 1242

Høg, E. 2009, Experimental Astronomy, 25, 225

Kitchin, C. R. 2020, Astrophysical techniques (CRC press)

Kovalevsky, J. 2002, Modern astrometry (Springer Science & Business Media)

Lindegren, L. & Bastian, U. 2010, in EAS Publications Series, Vol. 45, EAS Publications Series, 109–114

Perryman, M., Spergel, D. N., & Lindegren, L. 2014, ApJ, 789, 166

Zacharias, N., Finch, C. T., Girard, T. M., et al. 2013, AJ, 145, 44

[7] https://link.springer.com/book/10.1007/978-3-662-04730-9
[8] https://ui.adsabs.harvard.edu/abs/2009ExA....25..225H/abstract