A Giant Step: from Milli- to Micro-arcsecond Astrometry
Proceedings IAU Symposium No. 248, 2007
W. J. Jin, I. Platais & M. A. C. Perryman, eds.

doi:10.1017/S1743921308019881

Calibration of stellar parameters using high-precision parallaxes

A. G. Butkevich[1]†, A. V. Berdyugin[2] and P. Teerikorpi[2]

[1]Lohrmann Observatory, Dresden Technical University, D-01062 Dresden, Germany
email: alexey.butkevich@tu-dresden.de

[2]Tuorla Observatory, Turku University, FIN-21500 Piikkiö, Finland
email: andber@utu.fi, pekkatee@utu.fi

Abstract. Utilization of sub-milliarcsecond trigonometric parallaxes shifts the classical problem of calibration of stellar parameters to a new level of complexity. Derivation of stellar luminosity from the parallaxes is not a straightforward task with a number of statistical effects, such as Malmquist bias, to be taken into account. Different methods are to be used in order to derive parameters of luminosity function depending on the nature of underlying stellar sample. It is emphasized that any combination of astrometric parameters (i.e. parallaxes) and astrophysical ones must be handled carefully to avoid or reduce statistical effects, which otherwise may seriously affect the astrophysical applications.

Keywords. stars: distances, stars: fundamental parameters, stars: statistics, methods: statistical

---

The high-quality parallaxes provided by Hipparcos have allowed astronomers to improve the luminosity calibration for various stellar types. It has also given rise to numerous studies in this field, mainly focusing on the statistical handling of trigonometric parallax data, which appeared to be more complicated than anticipated. One of statistical effects is related to fine details of the Malmquist bias, such as its dependence on distance. This effect had been known for a long time in extragalactic astronomy where redshifts are used as non-photometric distance indicators. One distinction between the stars and galaxies, from the viewpoint of statistics has been the different relative accuracy of distances. Redshifts give a rather good relative distance precision, typically 5-10%, while accurate parallaxes, until Hipparcos were known for a small number of nearby stars. Therefore this type of bias simply was not relevant prior to Hipparcos. With Gaia its analysis will be increasingly important.

The well-known formula for the Malmquist bias states that the mean absolute magnitude calculated for a magnitude-limited sample from a stellar population having Gaussian luminosity function with intrinsic mean M_0 and scatter σ is

$$\overline{M} = M_0 - 1.38\sigma^2 \,.$$

This formula, has to be applied with caution. Malmquist (1922) derived it in his classical study, assuming that the star distribution is spatially uniform.

The Malmquist bias originates from a simple but subtle selection effect: the more distant objects we consider, the brighter objects we get, but at larger distances there is the higher spatial volume. In a magnitude-limited sample this bias at a fixed distance cuts off the stars from the faint side of the luminosity function (Teerikorpi 1975; Sandage 1994). The difference between the mean absolute magnitude calculated for the remaining

† On leave from Pulkovo Observatory, 196140 Saint-Petersburg, Russia.

part of the luminosity function and the true intrinsic mean M_0 represents the distance-dependent Malmquist bias.

A quantitative treatment of the distance-dependent Malmquist bias developed by Teerikorpi (1975) and generalized by Butkevich, Berdyugin & Teerikorpi (2005a) implies that, under the following assumptions: (a) there is no interstellar absorption; (b) the luminosity function obeys a Gaussian law with a mean M_0 and a scatter σ and does not depend on distance; (c) the considered stellar sample is complete up to a cutoff apparent magnitude $m_{\rm lim}$; the mean absolute magnitude at a fixed parallax π is given by

$$\overline{M}\left(\pi\right) = -\sigma\sqrt{\frac{2}{\pi}}\frac{\exp\left[-\left(M_{\rm lim}\left(\pi\right) - M_0\right)^2 / \left(2\sigma^2\right)\right]}{\operatorname{erfc}\left[-\left(M_{\rm lim}\left(\pi\right) - M_0\right) / \left(\sigma\sqrt{2}\right)\right]} ,$$

where $M_{\rm lim}\left(\pi\right) = m_{\rm lim} + 5 + 5\lg\pi$.

The first empirical demonstration of the distant-dependent Malmquist bias using the Hipparcos parallaxes was done by Oudmaijer, Groenewegen & Schrijver (1999) who pointed out a correlation between the derived absolute magnitude and parallax for a sample of K0V stars with high precision parallaxes. Butkevich, Berdyugin & Teerikorpi (2005b) confirmed this result and showed that the bias behaves in a manner consistent with theoretical predictions.

The bias appears to start from a certain distance, which divides the entire distance range into the regions affected and not affected by the bias. The unbiased region, which is also called unbiased plateau, represents a volume-limited subset of a total sample. Detection of the boundary of the unbiased plateau is not a straightforward task because its position depends on the luminosity function which usually is unknown. Even if we assume some functional form of the luminosity function, say, a Gaussian, one should know its scatter σ in order to calculate where the boundary lies. Fortunately, the unbiased region may be recognised by visual inspection of the Spaenhauer diagram. Moreover, one may simply estimate where the bias is important. Let parallax π_0 and distance r_0 correspond to the condition $M_{\rm lim}\left(\pi_0\right) = M_0$:

$$\pi_0 = 1/r_0 = 10^{\left(M_0 - m_{\rm lim} - 5\right)/5} .$$

The bias may be neglected if $\pi > \pi_0$, and should be taken into account if $\pi < \pi_0$.

This criterion and assumed astrometric accuracy allow to predict which part of the HR diagram would be affected by the bias at a given distance. It is worthwhile mentioning that the interstellar extinction can seriously influence the bias at large distances, say, beyond 1 kpc.

Acknowledgements

This study has been supported by the Academy of Finland (the projects 'Fundamental questions of observational cosmology' and 'Study of circumstellar and interstellar medium with polarimetry').

References

Butkevich, A. G., Berdyugin, A. V., & Teerikorpi, P. 2005a, *MNRAS* 362, 321
Butkevich, A. G., Berdyugin, A. V., & Teerikorpi, P. 2005b, *A&A* 435, 949
Malmquist, K. G. 1922, *Lund Medd. Ser. I* 100, 1
Oudmaijer, R. D., Groenewegen, M. A. T., & Schrijver, H. 1999, *A&A* 341, L55
Sandage, A. 1994, *ApJ* 430, 1
Teerikorpi, P. 1975, *A&A* 45, 117