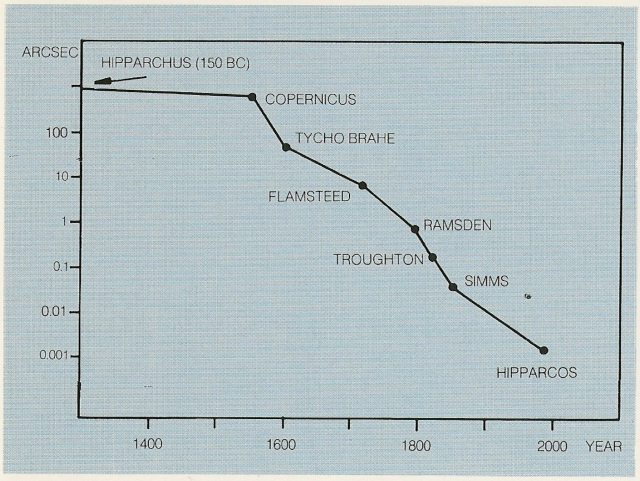
Appendix to : Contribution to the history of astrometry No. 7 25 November 2008

Appendix to
Astrometric accuracy during the past 2000 years

by Erik Høg



The observational error in astronomical measurement of stellar and planetary positions shown as a function of time. (Courtesy of D. Hughes.)

Fig. 2. Accuracy diagram: Hipparcos-1985

Hipparcos-1985

This diagram appeared in June 1985 in the brochure ESA BR-24, called Ad Astra Hipparcos. I recently wrote to David Hughes as quoted below under Mineur-1939. I then asked Michael Perryman who answered: "I recall seeing such a plot by David Hughes (as he confirms in his mail) although I do not remember where (New Scientist, perhaps?). The first time we used it in Hipparcos that I am aware of was in "Ad Astra" (BR-24, June 1985, p8), but perhaps before. The credit there is given as D. Hughes, but I have no recollection whether the editor (Norman Longdon) had any correspondence with Hughes in preparing that version." See the discussion of this diagram at Chapman-1983.

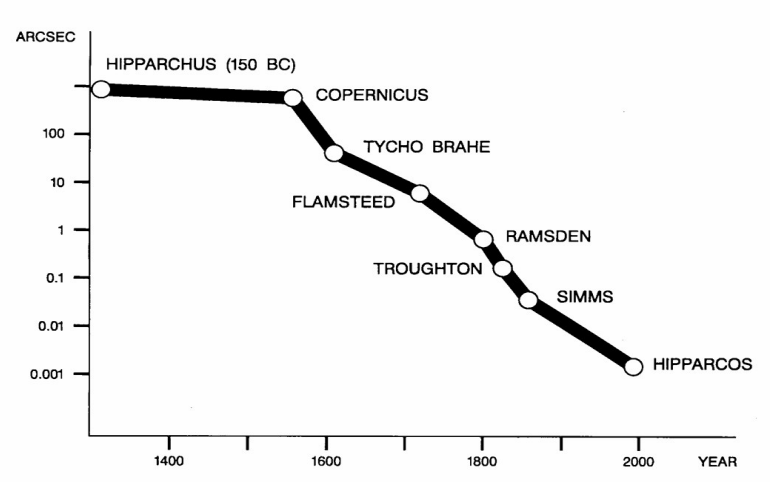


Fig. 3. Accuracy diagram in ESA SP111. Hipparcos-1989.

Hipparcos-1989

This diagram appeared in ESA SP-1111 as FIG. 1.1 on p. 3, and it is nearly identical to Hipparcos-1985.

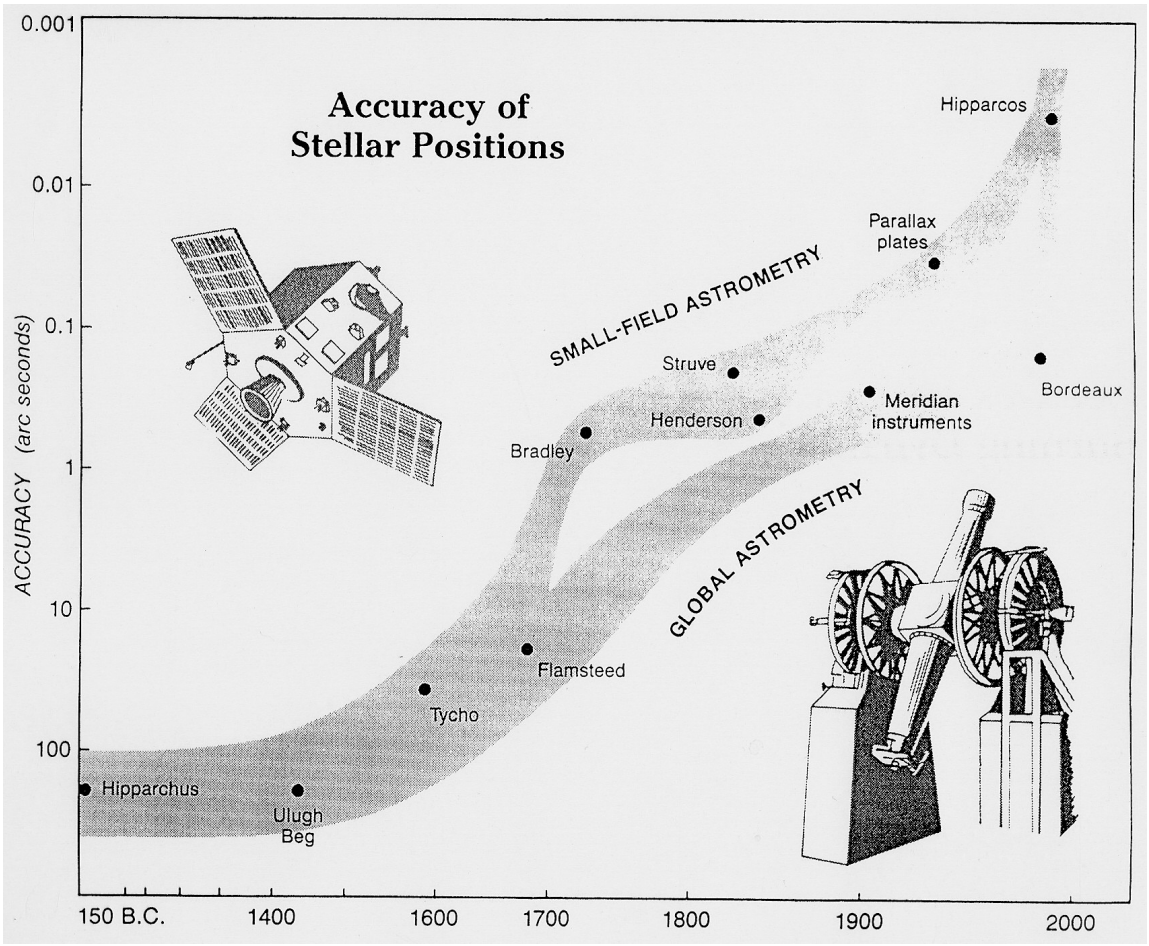


Fig. 4. Accuracy diagram: Kovalevsky-1990.

Kovalevsky-1990

I believe that Jean Kovalevsky presented the diagram at the Cospar meeting in Den Haag about 1990. I thought at that time that it needed some check and improvement, but only in 1995 did I study this matter carefully and elaborated the new diagram, Høg-1995.

Jean sent me his diagram in October 2007 as I had asked him. He wrote: "I found the one that I append. but I do not know when I projected it, and even whether I draw it or borrowed it from somebody else." I have scanned the viewgraph and I must apologize for any deterioration hereby introduced.

The values plotted in the diagram Kovalevsky-1990 are: Hipparchus and Ulugh Beg both with 200", Tycho 60", Flamsteed 20", Bradley and Henderson 0.5", Meridian instruments 0.5", Struve and Bordeaux 0.2", Parallax plates 0.03", and Hipparcos 0.004". The values for Hipparchus, Ulugh Beg, and Hipparcos deviate a lot from those in other diagrams.

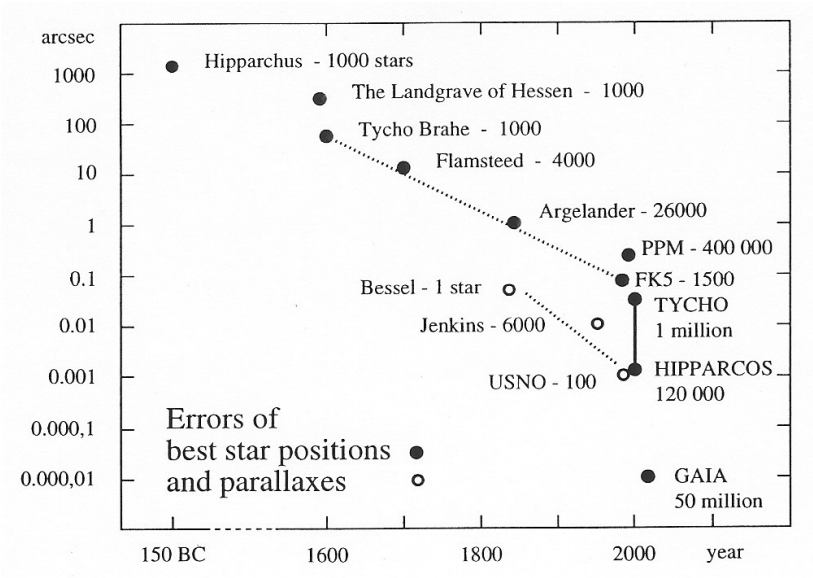


Fig. 5. Accuracy diagram: Høg-1995.

Høg-1995

This diagram was made in 1995, I profited thereby from correspondence with Michael, Lennart and Uli. It appeared in 1997 (with courtesy E. Høg) as Fig. 1 in Volume 2 of ESA SP-1200, the Hipparcos and Tycho Catalogues from where Fig. 5 has been scanned.

The diagram is included in the Gaia information sheet by Jos de Bruijne, dated 2006-02-13, but there the UCAC2 has been added with 58 million stars at 0.04", and the 50 million stars for Gaia is changed to 1000 million. A change of Tycho into Tycho-2 with 2.5 million stars could also have been made. Furthermore, I found on the internet that the median accuracy would be about 0.07" for UCAC2 while the 0.04" shown in Jos' diagram may apply to brighter stars.

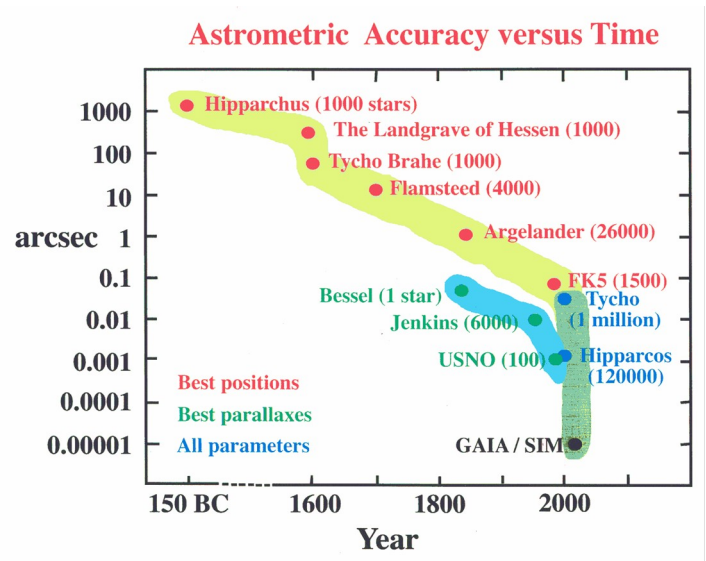


Fig. 6. Accuracy diagram: ESA-1998

ESA-1998
This diagram with colours was produced by Michael Perryman for a technical presentation around 1998.

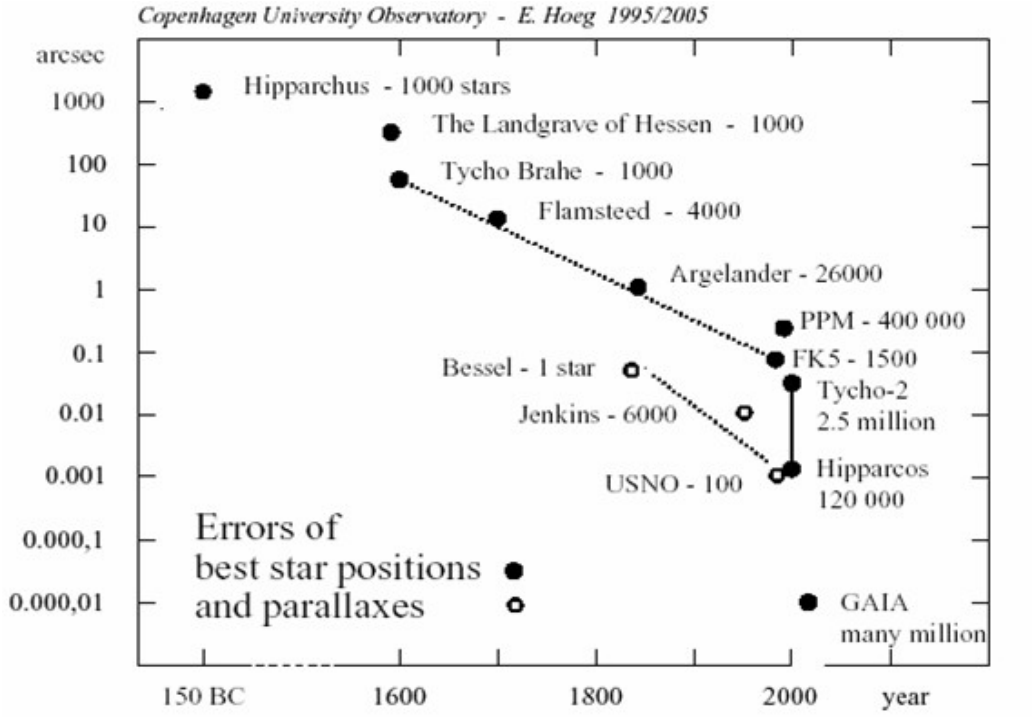


Fig. 7. Accuracy diagram: Høg-1995/2005

Høg-1995/2005
This is a modification from 2005 of the original from 1995, Tycho-2 is now included.

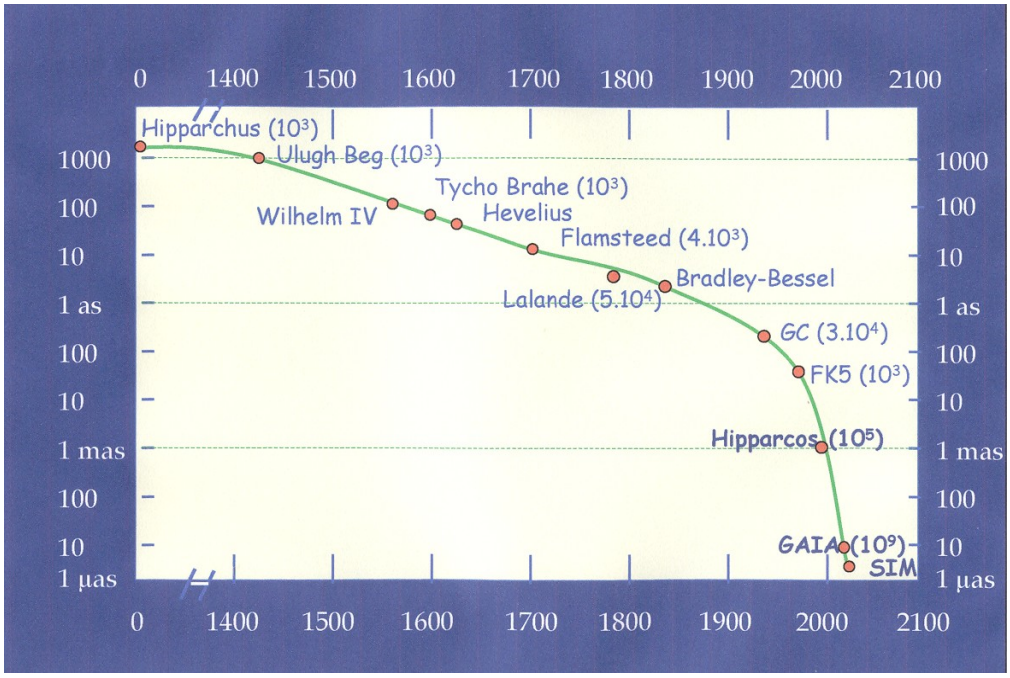


Fig. 8. Accuracy diagram: Turon-2007.

Turon-2007

This diagram was used by C. Turon in Shanghai 2007 during the presentation Turon & Arenou (2008). She kindly gave me the diagram and she wrote on 8 Nov 2007: "The diagram of p22 is one which has been used and modified by so many people .... I do not know whose original idea it is. If my memory is correct (I cannot check as I do not have this document at home), one version of this graph is in the "Hipparcos phase A report". An updated version is in the Gaia information sheet "Astrometric Accuracy Assessment" (with no reference either). It is why I did not put any "courtesy by". And I do not want that it is quoted as "Courtesy by C. Turon" as this is clearly a collective work. We will re-check the position of each of the points." Later on Turon has add that this graph, originally by Mignard, should be put into its context in Shanghai where it was briefly shown *only* for illustration, just to show the drastic improvement provided by space astrometry, not as a careful historical work.

According to Arenou (2008), the same diagram has been used in presentations by F. Mignard (18 May 2004) and by S.A. Klioner (31 March 2006), and it has originally been made by Mignard. The two presentations are here:
http://www.ari.uni-heidelberg.de/gaia/arc-of-current-t/mignard_gaia_ari.ppt
http://www.jb.man.ac.uk/ska/gravmeeting06/talks/klioner.ppt

The accuracies are read from the plot as follows: Hipparchus 1500", Ulugh Beg 1000", Wilhelm IV 120" Tycho Brahe 60", Hevelius 40", Flamsteed 12", Bradley-Bessel 2", Lalande 3", GC 0.2", FK5 0.04", Hipparcos 1 mas, GAIA 0.01 mas, and SIM 0.005 mas.

Some inconsistencies are noted: The point for Hevelius is misplaced at 1620 but belongs at 1670, Bradley-Bessel is misplaced at 1830 but belongs at 1755 when the observations were made. GC is placed at about the date of publication 1937 with 0.2", but at that time the error was 0.37". FK5 is placed at 1970, but the 0.04" corresponds to the mean epoch which was 1950. If these things were corrected the dots would move away from the smooth curve on which they are presently lying.

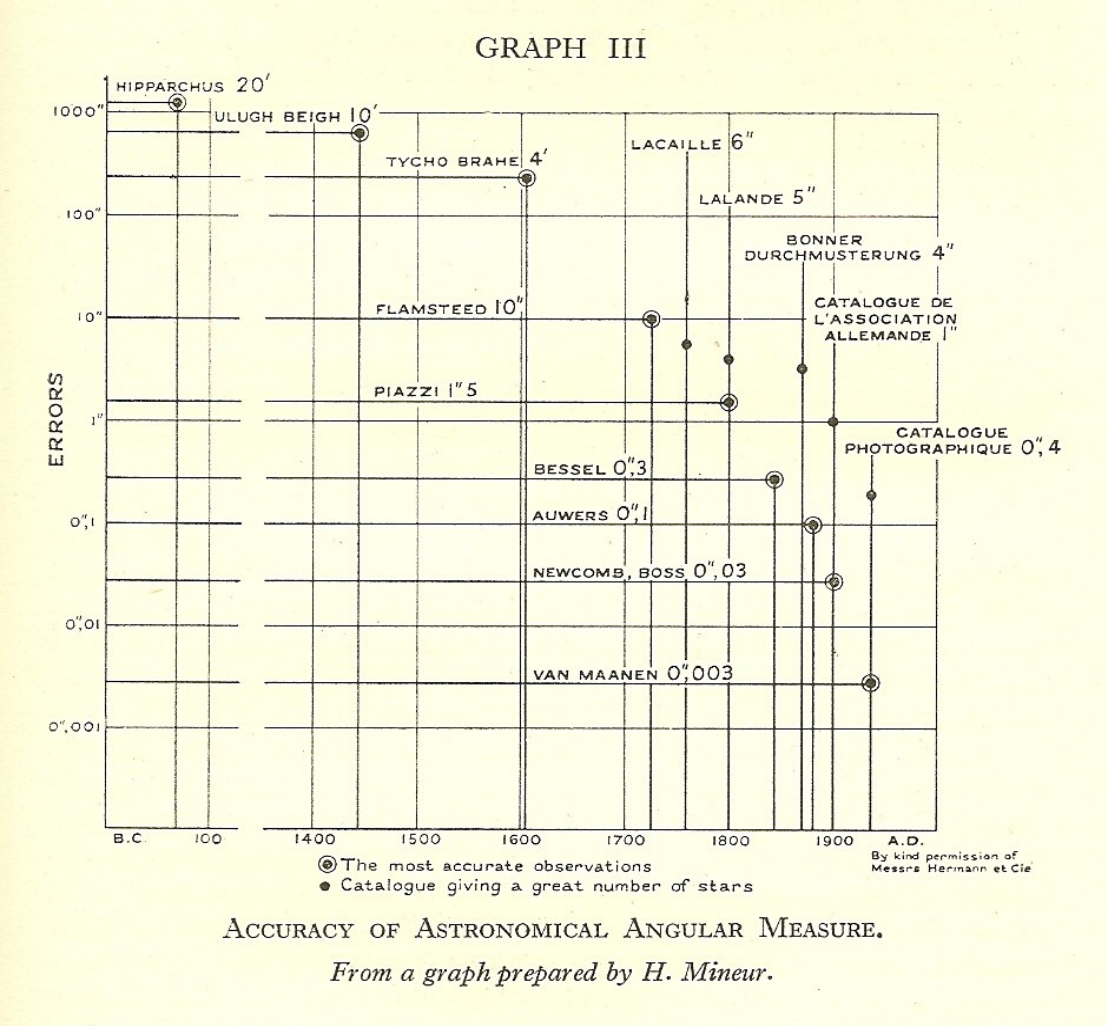


Figure 9. Accuracy diagram: Mineur-1939.

Mineur-1939

I am grateful to Professor David W. Hughes for drawing my attention to this diagram in Pledge (1939) in a mail of March 2008. I had asked him whether he knew the diagram shown here as Hipparcos-1989. David Hughes has no recollection of this specific graph from the Hipparcos publication, but he did produce a very similar graph for his history of astronomy students at the University of Sheffield, and this might be where the author (of Hipparcos-1989) got the idea from, he concludes.

The diagram is shown on p.291 in Pledge (1939), facing a page where the first measurement of stellar parallaxes about 1838 is mentioned on just six lines. No reference to the diagram is made in the text and no explanation is given other that on the graph itself. The reader can see the general trend towards better accuracy by a factor of 100,000 since Tycho Brahe, but some numbers are rather strange. The value 0.3" for Bessel is plotted as "most accurate observation" and probably means his parallax, but his measurement of the parallax had 5 times smaller error. Hipparchus is included with 20' which is his error within constellations while the error over the sky is 1 degree (see above). For van Maanen is given 0.003" which must be for relative astrometry, perhaps for his infamous measurements of proper motions in the Andromeda galaxy. I do not consider any specific number in this diagram as very trustworthy, but it should be credited as the first known attempt to make such a diagram.

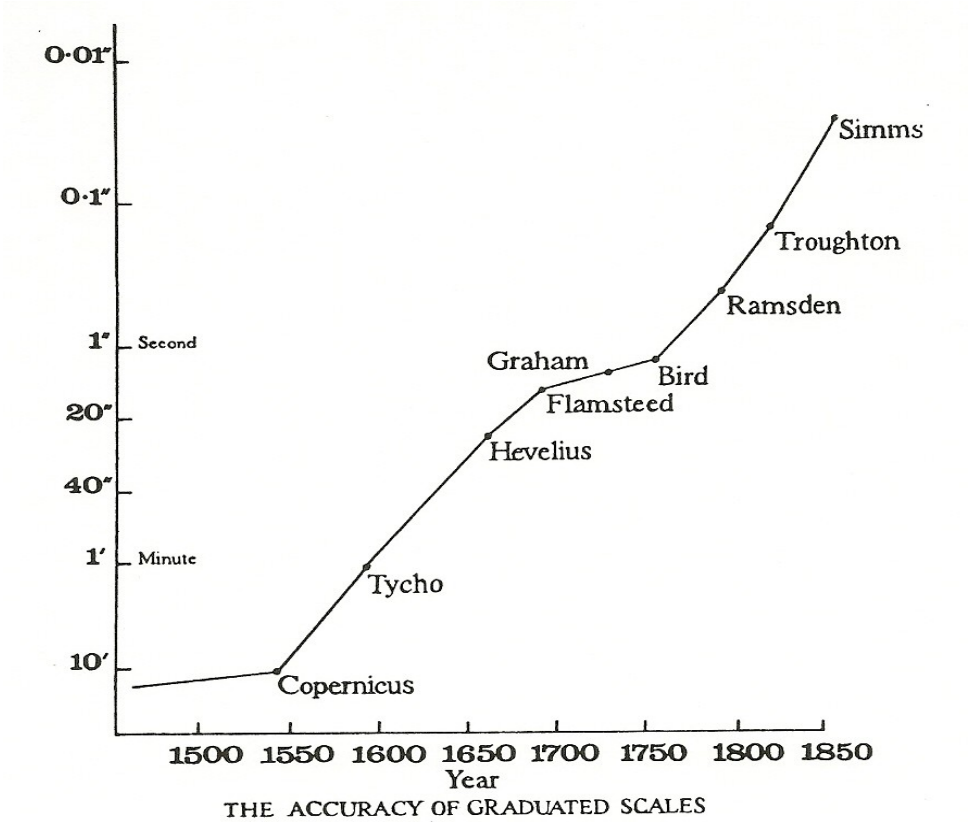


Fig. 10. Accuracy of graduated scales: Chapman-1983.

Chapman-1983

I found of this diagram in May 2008, and that suddenly made me understand the whole confusing story about the diagrams. I have now understood where the misunderstanding came in, but I do not know who made the mistake, and I do not try to find out.

The diagram by Chapman (1983) was prepared independently of the one by Mineur, Chapman writes. It shows the accuracy of *graduated scales*, as stated on the graph and explained in the accompanying text.

Nevertheless, this very diagram has been taken to mean the accuracy of star positions in the first diagrams used for the Hipparcos mission in 1985 and onwards, but many other errors than that of the graduated scale enter in an astrometric observation. For the use with Hipparcos the diagram has been turned upside down. More essential changes are that Hipparchus is included in Hipparcos-1985, the points for Hevelius, Graham and Bird have been omitted, and of course Hipparcos is included with 0.002” which was the expected accuracy in 1983.

The value of 0.025” for Simms at 1850 represent, according to Chapman, the precision of reading a divided circle with six microscopes and taking the average. This does probably not take division line errors into account which can be much larger. By 1850 the error of a position in a catalogue was about 1”, e.g. Argelander in Høg-2008, thus 40 times larger than the error from reading the circle.

In Hipparcos-1985 the point for Ramsden is placed at 0.9” while it is here at 0.4”. But there can be no doubt where the points in Hipparcos-1985 came from.