A Previously Unrecorded Medieval Latin Astrolabe and Evidence for a Mid-fourteenth Century Instrument Workshop

John Davis[1], Bert Degenaar[2], Arie de Ruiter[3], Rob van Gent[4], Arie Pappot[5] and Angelo Agostino[6]

Abstract

A previously unknown medieval Latin astrolabe is described in detail. Although its condition is far from perfect, detailed study shows that not only was it made to a high standard of workmanship and very well engraved, it can be linked to a group of larger astrolabes, probably from Italy in the mid to late 14th century, some of which have been described by Tullio Tomba. Various features of the overall style, the palaeography, the stars, and the metallurgy have been identified which allow the members of this group of astrolabes to be linked. Other derivative astrolabes from slightly later in the medieval period share some of these features and lead to the belief that there was an important workshop in northern Italy which produced instruments over a significant period. It is also possible that these features had some influence on the style of astrolabes produced in the Parisian workshop of Jean Fusoris.

Introduction

Knowledge of how and where astrolabes – and other scientific instruments – were made in 14th-century Northern Europe is very scarce. With the exception of the Parisian workshop of Jean Fusoris at the end of that century and into the beginning of the 15th (which was discovered and described by Emmanuel Poulle[1]), we do not know by whom or where the several tens of medieval astrolabes now in museums and private collections were made. Whether they were produced by individual craftsmen making one-off instruments or large establishments making many devices over an extended period, either for individual clients or for general sale, is totally lost to history. Careful and detailed study of all aspects of the corpus of astrolabes may gradually fill in some of these details.

A small and badly neglected astrolabe, previously unrecorded, has recently become available for study: at first sight it did not look particularly significant but closer inspection found some probable links to other instruments known in museum collections. This astrolabe, seen in Fig. 1, is now in the Zuylenburgh Collection in Utrecht, The Netherlands[2], and on careful study can be seen to have originally been of very high-quality workmanship despite its small size. The technical details of its astronomical and calendrical scales, together with its metallurgy, stylistic features, and its engraving hand, all provide clues to its origins and it can be seen to share many of these details with several other, larger, astrolabes. Some of these clues provide indications of how the style may have developed from an earlier English workshop and then later influenced Fusoris in France.

Provenance

The Zuylenburgh astrolabe first came to light in 2016 at the annual ‘Grande Braderie’ (antiques market) in Lille, Northern France. It was purchased for a very low sum by a dealer who recognised that it was an old scientific instrument though the seller thought it might be a reproduction. At that time, the rete was inside the mater and covered by the plate. Judging by its condition, it is possible that it had been found buried in an archaeological or metal detecting context although the relative lightness of the corrosion/patina makes it more likely that it has been abandoned in a damp drawer for many decades or even centuries. The first museum (in The Netherlands) to which it was offered did not have funds available, so it was offered to the Zuylenburgh Collection where one of us (RvG) recognised its possible early date and importance. The astrolabe was on display at Zuylenburgh in 2018 when members of the Scientific Instrument

Fig. 1 (left) *Front and* (right) *back overall views of the Zuylenburgh astrolabe. The components are shown in the normal sequence.*

Fig. 2 (left) *The mater of the Zuylenburgh astrolabe showing the ghost image of the rete with,* (centre) *a close-up of the throne and* (right) *side view showing the laminar construction.*

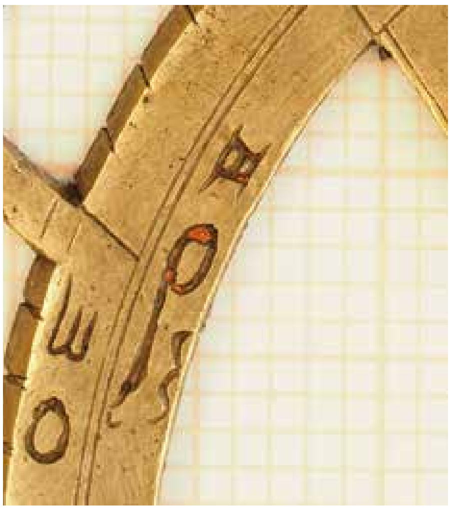


Fig. 3 *Close-up of the engraving on the rete showing traces of red infill in the engraving. Note also the abbreviation of Aquarius.*

Commission (SIC) visited, allowing Louise Devoy (National Maritime Museum, Greenwich) to see it and alert the authors to a potential collaboration. Its ownership in earlier centuries remains totally unknown.

Description

General, Mater

The Zuylenburgh astrolabe has a diameter of 93 mm, making it one of the smaller known European instruments (the astrolabe known as Caius B belonging to Gonville and Caius College, Cambridge[3], is slightly smaller at 88.1 mm). It currently comprises only a mater with suspension apparatus, a single removable plate, and the rete: the rule, alidade, pin and horse (wedge) are wanting. As can be seen, some of the surfaces are encrusted with corrosion products and a heavy tarnish. In addition, there are various hairline cracks in the mater due to intergranular or 'season' cracking: see the Metallurgy and Materials Analysis section below.[4] These are evidence of the hard life that the instrument has had and so have not been removed, but instead it has been conserved to prevent further degradation.

The mater has a total thickness of 4.1 mm and it is constructed from a copper-alloy backplate 1.5 mm thick with a partially-integral throne, to which is attached an annular limb and additional pieces to complete the throne – see Fig. 2. The inside of the mater (the womb) shows a ghost image of the rete in the tarnishing as a result of the long period during which the instrument was left assembled with the components in the wrong sequence. The limb is attached with rivets at approximately 30° intervals around the perimeter – those at the east and west points are particularly visible – as well as one holding the extra piece of brass attached for the throne. The rivets have been expertly inserted and have the same patination as both the front and the back of the mater. There is no engraving in the womb which has a depth of 2.6 mm which could thus be just sufficient to accommodate a second plate (now lost) though this is not certain.

The quite narrow limb is engraved with a degree scale [0]-360, numbered in 20s, clockwise starting at the top.

The throne is small and of the tri-lobed form found on many 14th-century European astrolabes but note the small right-angled protrusions between the lobes so that the overall shape is that of a 'barbed demi-quatrefoil' – this point will be returned to later. The suspension shackle (hoop) is a type sometimes known as an omega or 'headphone' style; the pivot has characteristic domed heads, slotted on one side – see Fig. 2.

One feature which can be observed by close examination of both the back of the mater and the rete is that there are remnants of a red infill, presumably of wax, in some of the engraved characters – see Fig. 3. Whilst it is often suspected that engraving would be filled routinely to enhance its legibility, this is one of the very rare cases on medieval instruments where evidence is still extant.[5]

Rete and Stars

The rete, shown in Fig. 4, has a diameter of 84.0 mm and a thickness of around 1.2 mm. It is well made but the solstitial (vertical) bar has snapped between the ecliptic circle and the lower equatorial arc leading to some distortion. The ecliptic circle is divided into the zodiac signs and marked in intervals of 6°, numbered only in 30s. The names of the signs are abbreviated as shown in Table 1.

The rete strapwork includes arcs of the equatorial circle both inside and outside the ecliptic circle. Note that astrolabes from the Fusoris workshop also have arcs in the southern ecliptic but they are concentric with it rather than being equatorial. The equinoctial (hori-

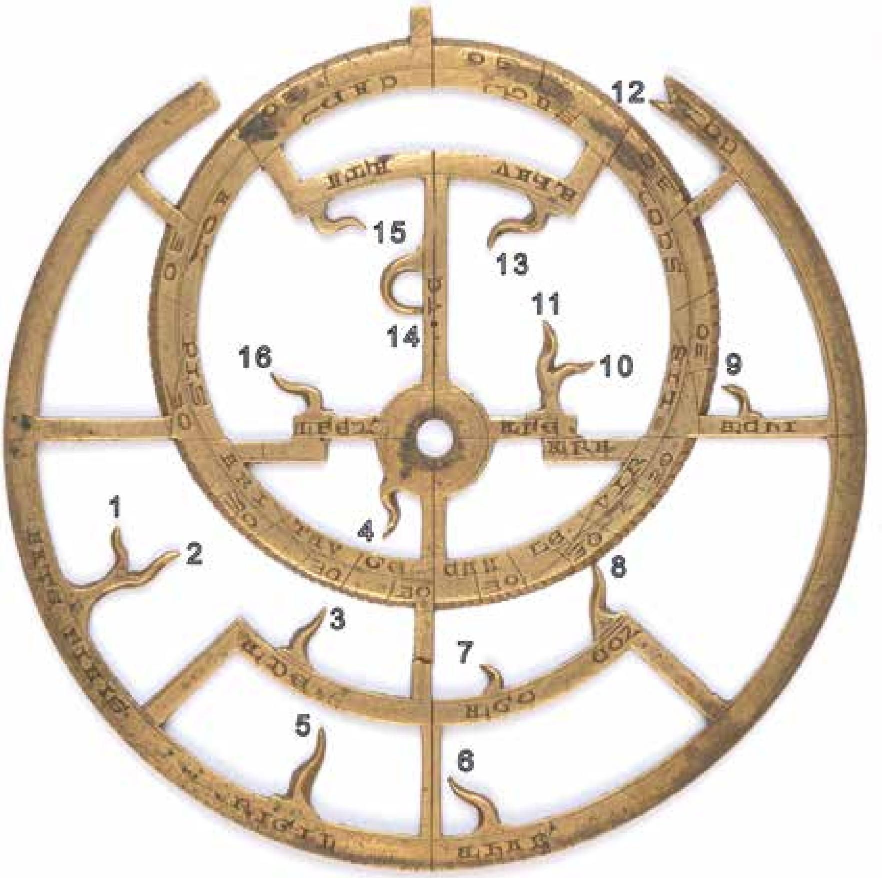


Fig. 4 (left*) The rete of the Zuylenburgh astrolabe. The stars have been numbered in order of increasing mediation (see Table 2); (*right*) close-up of the pointer for Batenkatoz and Finis fluxus, showing the engraving style, (*below*) the back, showing the division of the ecliptic.*

zontal) bar is counter-changed twice within the ecliptic circle and again at it: the solstitial (vertical) bar is counter-changed at the southern ecliptic and equatorial circles.

The rete has flame-shaped pointers for 16 stars, all but one of them named in Latinised Arabic and heavily abbreviated. Two of the pointers are for pairs of stars. The stars are listed in Table 2 together with their measured mediations (read off the ecliptic markings) and their declinations (calculated from the ratio of their radial distances to the equatorial radius). The table also lists the stars from Paul Kunitzsch's Type VIII star list[6] (also known as the pseudo-Masha'allah table[7]) which is presumed to be the most likely source of the data used by the astrolabe maker. In addition, Table 2 shows the same data for two other astrolabes with which we will compare the Zuylenburgh one. Note that the break in the solstitial bar has caused some distortion of the rete which affects, particularly, the measured mediations of some stars with southern declinations in the region of the break.

The star names are engraved very neatly in an all-capital Gothic style which makes extensive use of ligatures (particularly for 'AL') and omission symbols. These are discussed further later.

Fig. 4 also shows the back of the rete which, it can be seen, has the ecliptic circle fully divided; this is clearly the manner in which the star pointers were drawn. With independent measures of the diameters of the three principal circles (equato-

Table 1. The forms of the names of the signs on the Zuylenburgh and other astrolabes

MONTH	Zuylenburg	NMM AST0590	Milan #4516
January	IANV^{-}	IANVARI^{9}	IANV
February	FEBR^	FEBRVARI^{9}	FEBRV
March	MARC^	MARCI^{9}	MARCI
April	APRI	APRIL^	APRI
May	MARCI	MAIVS	MAI
June	IVNI^{9}	IVNI^{9}	IVN
July	IVLI	IVNI^{9}	IVLI
August	AVG^{9}	AVGVST^{9}	AVGVS
September	SEPT'	SETE^{-}B^{S}	XXT?
October	OCTO	OCTOB^{S}	OCTO
November	NOV^	NOVE^{-}B^{S}	NOVE^{-}
December	DECE^{-}	DECE^{-}B^{S}	DEC^{-}

rial, and the Tropics of Capricorn and Cancer) from both sides of the rete, six measures of the value of the obliquity used in the construction can be extracted, giving a value of 23.41° ±0.05°.[8] This leads to the suggestion that the maker was using a nominal value of 23½° taken from the Alfonsine Tables rather than the 24° found for Latin astrolabes using the Toledan Tables before around 1330.[9]

Plate

The single extant double-sided plate has a diameter of 84.0 mm and a thickness of around 0.7 mm although it is now no longer completely flat (see Fig. 5). There is a small anti-rotation tab which is unmarked. Because of the way the astrolabe was stored, possibly in damp conditions for an extended period, the two faces now look quite different but close inspection shows that the original stereographic projections would originally have been very similar. They are labelled for latitudes of 48° 48′ – almost certainly for Paris – and for 52°. Table 3 shows that the actual latitudes for which the plates have been drawn[10] agree closely to these values. The latter figure is a value sometimes used for London and also for Oxford although an 'improved' value for the latter in the second half of the century was 51° 50′ was introduced, probably by William Rede. Other alternatives for 52° lie in northern Europe and with this provenance it could equally likely be for a location in the Low Countries or central Germany – Utrecht or Magdeburg, for example. If a second plate were originally present, its latitudes could only be guessed at.

The three principal circles, for the Equator and the Tropics of Cancer and Capricorn, are drawn with dimensions shown in Table 3, which can be combined to reveal the value of the obliquity of the ecliptic used for the calculations.[11] These calculations produce a slightly lower value of the obliquity compared to that from the rete but the difference is not thought to be important.

The two stereographic projections have almucantars spaced at 5° and lines of azimuth at a spacing of 15° (dividing the full circle into 24 parts). This spacing of the azimuth lines is that suggested by Geoffrey Chaucer in this famous *Treatise on the Astrolabe* and found on several 'Chaucerian' and other astrolabes from the second half of the 14th century.[12] In addition, the northern (lower) part shows lines for the unequal (temporary) night-time hours. None of the lines are numbered. The equator circles have construction marks lightly scribed around a significant fraction of their circumferences. These marks are at an approximate spacing of 2.5°. Their exact use is not clear.

Back

The back of the mater is quite conventional for a Latin astrolabe of this period. Around the perimeter is a degree scale for measuring the altitudes (0-90-0 twice, divided to 2° with the zeroes E-W) and also labelled 0-30 for each of the twelve zodiac signs, arranged in

Fig. 5 *The two sides of the plate from the Zuylenburgh astrolabe.* Left, *52°*; right, *48° 48′.*

Table 2. Star positions as measured from the pointers on the Zuylenburg astrolabe, numbered in Fig. 4, and on two other associated astrolabes, compared to the full manuscript listing in Kunitzsch Type VIII. The values for the Milan #4516 astrolabe were taken from a non-ideal photograph. The stars are arranged in order of increasing mediation

Kunitzsch VIII							Zuylenburgh astrolabe				NMM AST0590 astrolabe				Milan #4516 astrolabe[2]			
No	Sign	Name	Bayer[1]	Mediation		Dec	No	Name	Med	Dec	No	Name	Med	Dec	No	Name	Med	Dec
1	Ari	Mirach	β And	Ari	0.12	32.5					1	MIRAC	7.2	33.1	1	MIR	4	27.1
2		Batenkaytoz	ζ Cet	Ari	18.5	-13.5	1	BATE’	16	-12.5								
3		Pantenkaitoz	ζ Cet	Ari	20	-14					2	PANTAK	20	-14.1	2	PANTAK	17	-13.7
4		Enif	α Ari	Ari	22	23.5					3	ENIF	22.4	32.6				
5		Finis fluxus	ν Eri	Ari	25	-4.5	2	FINIS	26	-2.9	4	FINIS FLUX[9]	25	-4.6	3	FINIS FLUX	19	-4.7
6	Tau	Menkar	α Cet	Tau	6	1					5	MENKAR	6	0.7	4	MENKAR	5	1.7
7		Algenib	α Per	Tau	10	49					6	ALGENIB	8.3	48.7	5	ALGE	10	47.6
8		algetenar	γ Eri	Tau	22	-16					7	AVGETENAR	21.5	-15.9				
9		Aldebaran	α Tau	Tau	29	14.5	3	ALDE	29.5	15.5	8	ALDEBARAN	29.6	14.1	6	ALDEBA	28	14.1
10		Alhaioh	α Aur	Gem	6	45	4	unnamed	5	43.2	9	ALHAY	6.2	44.2	7	ALHAIOT	5	45.2
11		Rigil	β Ori	Gem	11	-10	5	RIGIL	10.5	-9.3	10	RIGIL	11.2	-10.0	8	RIGIL	8	-10.3
12		Algeuze	α Ori	Gem	15	8					11	ALGEVZE	15	8.0	9	ALGEUZE	14	8.2
											12	unnamed	22	-13.8				
13	Cnc	Alhabor	α CMa	Cnc	3	-15	6	ALHAB’	2	-14.1	13	ALHABOR	4.1	-15.3	10	ALHABOR	3	-15.8
14		Razalgeuze	α Gem	Cnc	9	33												
15		Algomeyza	α CMi	Cnc	13	7	7	ALGO	10.5	7.3	14	ALGOMEYZA	12	6.9	11	ALGOMEI	14	7.6
16		Markep	ρ Pup	Cnc	21	-22.5					15	MARKEB	20.8	-22.8				
17		Egregez	μ UMa	Cnc	24	45					16	EGREGES	24	41.7	12	EGRE	25	44.2
18	Leo	Aldiran		Leo	6	-6					17*	ALDIRAN	5.5	-6.1	13	ALDIRAN	5	-5.0
19		Alfart	α Hya	Leo	13	-18.5					18	ALFART	12.5	-18.1	14	ALFART	11	-17.8
20		Calbalezed	α Leo	Leo	20	15	8	COR	19.5	15.0	20	COR LEO	20.4	12.6	15	COR LEO	19	13.3
21		Alrucaba	ν UMa	Leo	20	35					19	ALRVCABA	19.8	35.2				
22	Vir	Coruus	Ghost	Vir	1	-11					22	CORV[9]	0	-12.3	16	CORVUS	3	-10.6
23		Dubhe	α UMa	Vir	2	67[3]					21	DVBHE	0.5	67.7				
24		Denebalezed	β Leo	Vir	15	19.5					23	CAUDA LEO	15.5	19.1	17	CAU LE	17	19.9
25		Algorab	γ Crv	Vir	22	-13.5									18	ALGORAB	19	-14.5
26	Lib	Alchimec	α Vir	Lib	10	-7	9	ALCHI	11.5	-5.6	24	ALCHIMEC	10.6	-6.9	19	ALCHIMEC	10	-6.5
27		Bennenaz	η UMa	Lib	20	53					25	BENENAS	19.8	52.1	20	BENE	19	53.0
28		Alramech	α Boo	Lib	27	24	10	ALRA	27	21.6	26	ALRAMEC	24.5	24.1	21	ALRA	24	25.9
29	Sco	Alfeca	α CrB	Sco	16	29	11	ALFE	20.5	27.6	27	ALFECA	17	29.2	22	ALFECA	14	30.1
30		Alachil	β Sco	Sco	17	14												

31		Yed	δ Oph	Sco	26	-3					28	YED	26	-0.3				
32		Calbalacrab	α Sco	Sco	27	-23	12	COR	30	-23.1	29	COR SCOR	27	-23.2	23	COR SCOR	26	-20.9
33	Sgr	Alhaue	α Oph	Sgr	13	15	13	ALHAV	15	17.0	30	ALHAVE	12	14.4	24	ALHAVE	14	17.0
34		Rahtaben	γ Dra	Sgr	25	51					31	RAZTA	26	50.2	25	RAZTA	24	51.6
35	Cap	Wega	α Lyr	Cap	3	38	14	VE	3	38.2	32	VEGA	3	38.0	26	VEGA	2	37.2
36		Altair	αAql	Cap	16	7	15	ALTA	16.5	11.3	33	ALTAYR	15.8	7.1	27	ALTAIR	16	8.3
37		Delfin	ε Del	Cap	29	12.65					34	DELFI_	29	12.5				
38		Alrif	α Cyg	Cap	29	42												
39		Addigege	α Cyg	Cap	30	43					35	ADIGE	30	42.9				
40	Aqr	Libedeneb	δ Cap	Aqr	6	-22					36	LIBE	6	-22.4	28	LIBEDE	6	-19.9
41		Delfin		Aqr	10	6									29	DELFIN	10	12.9
42		Aldiran	α Cep	Aqr	10	59					37	ALDIRAN	9	58.0	30	ALDIRAN	14	59.3
43		Enifelferaz	ε Peg	Aqr	13	7												
44		Denebalgedi	δ Cap	Aqr	14	-19.65					38	DENEBAL	13.8	-19.1	31	DENEBAL	15	-18.2
45		Sceach	δ Aqr	Aqr	30	-19					39	CRVS	29.8	-18.8	32	CRUS	1	-17.2
46	Psc	Alferaz	β Peg	Psc	6	24	16	ALFER'	6	22.2	40	ALFER	5.8	23.3	35	ALFER	14	55.0
47		Mentichel	β Peg / β Cet	Psc	18	25												
48		Denebkaitoz	ι Cet	Psc	22	-10					42	DENEBK'	21.5	-10.3	34	DENEB	20	-9.0
49		Sceder	α Cas	Psc	18	53					41	SCEDER	17	52.8	33	SEDER	13	25.9

Notes

1. Modern designations taken from Kunitzsch, *Typen von Sternverzeichnissen in astronomischen Handschriften des zehnten bis vierzehnten Jahrhunderts* (Wiesbaden, 1966).
2. The parameters for Milan astrolabe #4516 were extracted partly from the published works of Tomba and partly from a less-than-ideal photograph so should be treated with some caution.
3. Substitute value from a variant manuscript of the table – see Kunitzsch's notes to the Type.

the standard form with the first point of Aries on the right hand side and running anticlockwise. Inside this is an eccentric civil calendar arranged with the parameters shown in Table 4. The calendar is divided uniformly in 2-day intervals throughout so in some months they mark the days 1,3,5... and in other months they are 2,4,6... depending on the number of days in the months. Outside this a ring marked 10,20,30 (or 28 or 31) days. The eccentric offset of the calendar circle was measured by 'reverse-engineering' an accurate photograph in a CAD system as 0.0331 (normalised to the calendar radius) which is equivalent to a modern orbital eccentricity of 0.0166, extremely (fortuitously so?) close to the calculated value of 0.017 for the 14th century. The direction of the offset is directly upwards towards 30° Gemini, which places perigee at 0° Capricornus (30° Sagittarius) on 18.5 December. The celestial longitudes for the entry of the sun into each of the months are in some places difficult to read accurately because of corrosion.[13] The results (Table 4) suggest that the calendar scale is closer to tables from late in the fourteenth century by, for example, Nicholas of Lynn, 1386, and by Jean Fusoris[14], *c.* 1400, than to those of Walter of Elveden's 1327 *Kalendarium*[15], or to the values that are attached as an Appendix to the pseudo-Masha'allah text.[16] However, since the astrolabe calendar is an eccentric one, the maker did not necessarily refer to a tabulated form when drawing it.

Inside the calendar is a double shadow square of 12 units divided by 2 and numbered by 6. The area above this contains the standard double unequal hour quadrant with the lines unnumbered.

Discussion and Comparison With Other Astrolabes

Close examination of the astrolabe shows it to be of a much higher standard than its initial appearance had suggested; in particular, the engraving style is both elegant and distinctive. Several other, larger, astrolabes quickly spring to mind as having a similar style – two are shown in Fig. 6. They are both listed in the Frankfurt International Instrument List (IIL)[17]: one is a privately-owned instrument currently on loan to the National Maritime Museum (where it has the number AST0590, Fig. 7), and which was unknown to Tullio Tomba (1923–2006). The other is on display in the Museo Civico d'Arti Applicati, Milan (inv. 265 – see Fig. 8).[18] Further investigations then led to two other astrolabes now in Italy and to two in Oxford. They have been briefly described by Tullio Tomba who very perceptively linked them together in a rather obscure Italian paper[19], though he did not speculate on their history. Tomba also noticed that two other astrolabes, one probably a slightly later copy but quite similar to this design, were now in Oxford having previously been part of the Billmeir Collection.[20] A further similar astrolabe which also has part of its northern

Table 3. The radii of the principal circles on the two projections on the plate and the derived value of the obliquity of the ecliptic

Plate engraving	Calculated latitude [1], degrees	Measured radii, mm			Calc. Obliquity[2]
		Cancer	Equatorial	Capricorn	
48G 48M	48.61°	16.99	25.89	39.3	23.32°
52G	51.98°	17.10	25.84	39.2	23.10°

Notes

1. Calculated from the centre position and radius of the horizon circle.
2. Average of three values taking the circle radii in pairs.

Table 4. Details of the calendar on the back of the Zuylenburgh astrolabe

Month	Sign	Sign as engraved on astrolabe	Degrees at beginning of month[1]					Differences (degrees)			
			Zuylenburg[2] astrolabe	p-Massa-halla[3] C13	Walter Elveden[4] 1327	Nicholas of Lynn[5] 1386	Jean Fusoris[6] c.1400	Zuy – pM	Zuy – Elve	Zuy - NicLyn	Zuy - Fus
January	Capricorn	CAPRI	19.5	17.47	18.48	18.97	18.00	1.2	1.52	-0.3	0.7
February	Aquarius	AQ¯RI[9]	20.0	18.88	19.88	20.73	20.33	1.1	-0.53	-0.7	-0.3
March	Pisces	PISC^	21.0	16.88	17.85	18.78	18.00	1.9	1.95	0.0	0.8
April	Aries	ARIES	20.5	14.25	18.35	19.27	18.47	4.6	1.42	-0.5	0.3
May	Taurus	TAVR^	20.0	16.25	17.30	18.22	17.50	1.2	1.07	-0.8	-0.1
June	Gemini	GEM¯I	16.5	16.22	16.93	17.80	17.00	1.2	0.42	-0.4	0.4
July	Cancer	CANC^	16.0	14.78	15.53	16.32	15.50	0.5	-1.15	-1.0	-0.2
August	Leo	LEO	15.0	14.00	15.22	15.92	15.50	1.5	1.23	-0.4	0.0
September	Virgo	VIRGO	16.5	14.58	15.32	15.92	15.25	1.1	1.37	-0.2	0.4
October	Libra	LIB¯¯	16.6	14.22	14.93	15.50	15.00	1.1	1.37	-0.2	0.3
November	Scorpio	SCORP¯	17.5	15.33	16.07	16.65	16.50	1.3	1.55	0.0	0.1
December	Sagittarius	SAGI	18.5	15.87	16.57	17.23	16.50	0.8	1.13	-0.5	0.2
						Average difference		**1.46**	**0.80**	**-0.43**	**0.22**
			Zuylenburgh date			**Std. dev**		**1.03**	**0.640**	**0.311**	**0.346**
Spring equinox		0° Aries	11.8 March								
Summer solstice		0° Cancer	12.5 June								
Autumn equinox		0° Libra	13? September								
Winter solstice		0° Capri-corn	12 December								

Notes

1. Taken from the noon value of solar longitude on the last day of the previous month. Values given as degrees; minutes converted to decimal degrees.
2. Read on the astrolabe from the dividing line between months.
3. Values taken from R.T. Gunther, *Early Science in Oxford,* Vol V. Chaucer and Messahalla on the Astrolabe, (Oxford: OUP, 1939) p. 198 derived from ms Ashmole 1796.
4. Taken from ms Corpus Christi Coll Cambs ms 27.
5. Taken from S. Eisner, ed., *A Treatise on the Astrolabe* (Variorum, Norman: University of Oklahoma Press, 2002).
6. Taken from Poulle (note 1).

Table 5. The 'Tomba group' astrolabes

No.	Astrolabe	Location	Inv. no	IIL/CCA1	Diameter, mm	Rete details2	XRF analysis
1	Zuylenburgh	Zuylenburgh	--	--	93	Simple; no Q; B	Y
2	Private collector (UK)	NMM, Greenwich	AST0590	#3059	220	1 Q; 1 d-Q; dragon; B	Y
3	Tomba A	Palazzo Madama, Turin	0922/b	#3203	222	1 Q; 5 d-Q; dragon	Y
4	Tomba B /Koelliker	Tomba/Koelliker collection	As 019	#4515	158	1 Q; 4 d-Q; dragon	N
5	Tomba C (Bonhi de Portanaris)	Milan Civiche Raccolte di Arte	265	#4516	146	1Q; 1 d-Q	N
6	Billmeir 17[3]	Ox HSM	54330	#410	114	Simple; no Q; B. Fusoris type	Y
7	Billmeir 175	Ox HSM	47615	#2043	140	1Q; 1 d-Q; dragon	Y
8	Sotheby's June 1986 Lot 124	Unknown	--	--	167	Simple; no Q; B, Fusoris type	N
Related but not part of main group							
9	Billmeir 174	Ox HSM	36338	#2042	117	later copy?	Y
10	Lewis Evans 21/2063	Ox HSM	41468	#168	152	Simple; dragon; Later?	Y
11	Nuremberg 'Hollandia'	GNM	WI 6	#548	144	2 quarter-Q; dragon	N
12	Nuremberg	GNM	WI 21	#547	110	1 Q; 3 d-Q en-graved dragons	N

Notes

1. IIL = International Instrument List. CCA = Computer Checklist of Astrolabes.
2. Q = quatrefoil on rete; d-Q = demi-quatrefoil; dragon = dragon's head on Capricornian frame. B =break on the solstitial bar.
3. This astrolabe had 4 plates. One of them, for 38°/40°, is of a different alloy to the other three and has no azimuth lines.

solstitial bar missing was sold by Sotheby's in 1986.[21] As a consequence, we have dubbed these instruments, including the Zuylenburgh astrolabe, as the 'Tomba group' in honour of this pioneering twentieth-century Italian collector and scholar.[22] A list of the astrolabes currently identified as belonging to the Tomba group and probably all produced in the same workshop is shown in Table 5.

In 1966 Tomba published an article describing two of the astrolabes then in Milan. One was in his own collection which later passed to the Koelliker Collection, (inv. A019[23]) and the other was the one in the Milan Civiche Raccolte di Arte. He linked them to a common workshop and ascribed them to the 14th century.[24] Emmanuel Poulle attacked Tomba's hypotheses[25] and ascribed them to the 15th century and declared they were dissimilar, leading to a rather rancorous reply.[26] We believe Tomba was essentially correct in his conclusions though some of Poulle's objections – particularly regarding use of the First Point of Aries for dating – are valid.

The points of similarity which most of this group of astrolabes share and which lead us to believe that they were all made in the same workshop, probably by more than one hand but with a common training, are listed below. It should be pointed out that the Zuylenburgh astrolabe is missing one of the major points in the list in that its rete does not feature quatrefoils or demi-quatrefoils; however, this can be accounted for by its small size – it does, though, share most of the other key features.

* Shape of throne – three lobes with barbs or shoulders – 'barbed demi-quatrefoils'. This is perhaps the most easily visible feature of the design. In most cases, the inner circular borders of the lobes are engraved together with a prominent mark in the centres of the lobes.

* 'Omega', Ω (sometimes called 'stirrups' or 'headphones') style suspension with domed ends to the pivot and a simple ring.

* The strapwork bars on the rete which connect the ends of the outer, Capricornian, ring to the ecliptic circle are graceful arcs rather than straight struts.

* Various designs of the rete strapwork incorporating one or more quatrefoils, and demi-quatrefoils at the ends of the horizontal and vertical bars. These do not appear on the smaller instruments (Zuylenburgh, Oxford HSM 54330 and Sotheby's).

* The centre of the ecliptic circle is identified by a small dot or circle and arcs from the Equatorial and Tropic of Cancer circles can be seen crossing the ecliptic.

* The equinoctial (horizontal) bar on the rete is usually counter-changed twice inside the ecliptic circle and again at the circle itself.

* The inscriptions on the rete and the mater are in very well-controlled all-capital Lombardic style (as opposed to the uncial characters used on many 14th century astrolabes, or the 'spikey' Gothic script seen on several instruments by Jean Fusoris). The inscriptions are often enclosed between a pair of dots (•)

* The engraver frequently makes use of ligatures with that for AL invariably used at the start of the Arabic star names and even sometimes at the end of words.

* The engraving also frequently uses omission symbols to save space where letters have been left out. This is quite standard on medieval Latin astrolabes at the ends of words

Fig. 6 *The fronts of three astrolabes from the 'Tomba Group' showing their relative sizes.* Left to right*: NMM AST0590; Milan #4516; and the Zuylenburgh astrolabe.*

Fig. 7 *Front and back of the privately-owned astrolabe #3509 in the National Maritime Museum (inv. no. AST0590).*

but the Tomba group uses a far wider range of symbols than is normal, more akin to those found in contemporary manuscripts.[27] See Fig. 9. These symbols are used here inside words, as well as the standard 9 - symbol used on other astrolabe designs where words are truncated, usually but not always ending in -us. Note also the 'Q^{w}' of 'Aquarius'. Another characteristic is the 'N' drawn as a square box with an added diagonal.

* The stars on the rete are taken from Kunitzsch's Type VIII, including some variant forms (see below).

* The back of the retes show unusually extensive layout lines, including a full division of the ecliptic circle. On the front as well as the back of the retes, the centre for the ecliptic circle is prominently marked.

* The star pointers are mainly flame shaped with a sculpted profile. (Note that OxHSM inv. 47615, which appears to be an unfinished later copy of Tomba's #4516, has some pointers with flat 2-D shapes awaiting the final filing to the 3-D profile shown by the others.) Some pointers are in pairs (or even triples) with a 'snake's tongue' or 'hammerhead' appearance.

* On the Zuylenburgh, AST0590, HSM 54330 and Sotheby's 1986 retes, the vertical solstitial bar has snapped or is completely missing

Fig. 8 *Front and back of astrolabe #4516 in the Museo Civico d'Arti Applicati, Milan (inv. 265).*

Fig. 9 *Close-up montage of some of the engraved omission symbols on the Zuylenburgh astrolabe. Images 1-6, rete; images 7-16 astrolabe back.*

just to the north (i.e., below) of the ecliptic circle. Whilst this *could* be coincidence and is certainly not a design feature, it may point to a consequence of the material annealing and cutting process.

* The construction method uses a riveted backplate which is quite standard for larger astrolabes but for smaller instruments a cast mater is also commonly found, for example on some 'Chaucerian' astrolabes.

* The marker for 0° Capricorn at the top of the ecliptic (the al-Murî) is sloped to the right of the line with a decorative ogee-shape (though not on the Zuylenburgh example).[28]

* The central hub of the rete is marked with clear horizontal and vertical diameters and, on the larger members of the group, have the names of several stars placed circumferentially between two borders. The centre of the hub is thus left clear for the end of the rule.

* The plates give their latitudes with an unusual and characteristic abbreviation of L— 'Latitudo' see Fig. 10. Note that the Zuylenburgh astrolabe does not use any symbol.

* The equator circles of the plates carry light construction marks at approximately 2.5° intervals around parts of their circumferences. This feature is rare amongst medieval astrolabes but can be clearly seen on the Zuylenburgh and AST0590 instruments.

* The large majority of the astrolabes use the eccentric form of the civil calendar. Whilst this is also stan-

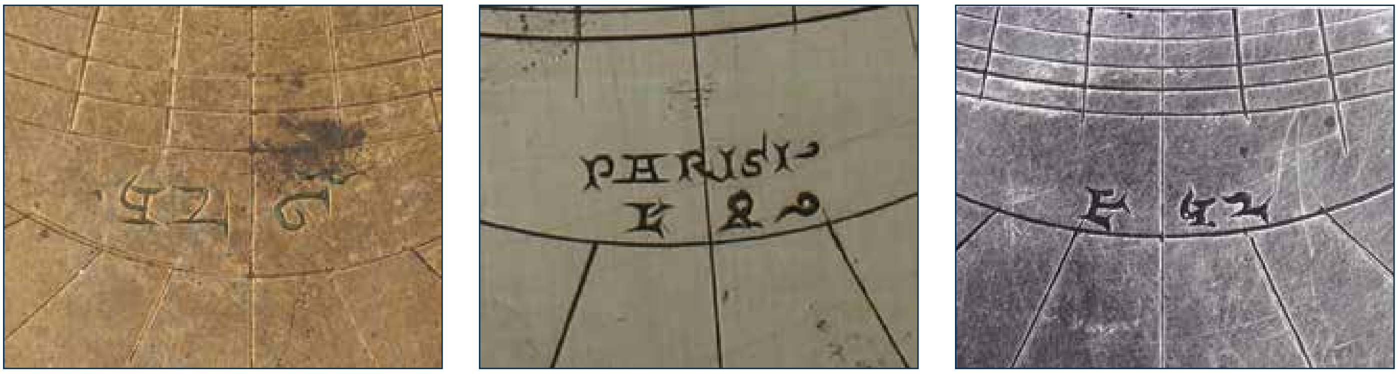


Fig. 10 (left) *Detail from the plate for 52° from the Zuylenburgh astrolabe compared with* (centre) *the engraved latitude from AST0590 (authors' photo) and* (right) *#4516 (Milan) taken from Tomba & Brusa, p. 38.*

Fig. 11 (top) *The head of a dragon on the AST0590 rete and* (bottom) *the shaped end to the ring on the Zuylenburgh astrolabe.*

dard on English astrolabes from the earliest part of the 14th century and continued to be used into the 15th century in mainland Europe (for example, by Fusoris), in England it had been replaced by the concentric form by the mid-14th century. On both the Zuylenburg and AST0590 astrolabes, the offset of the centre has been applied in the direction of 0° Cancer and the eccentricity is very close to the true value for the period, slightly larger than the traditional value of 1/32 described by pseudo-Masha'allah. The dates of the entry of the sun into the signs are, perhaps surprisingly, significantly closer in these two cases to the values of the *Kalendaria* of Nicholas of Lynn and Jean Fusoris than to other tables of the earlier 14th or later 15th centuries.

* The general style of the engraving is similar on these astrolabes – for example, the number '3' has a long lower leading serif and the 'R's are shaped like a modern '2'. An exception to this is OxHSM inv. 47615 which thus appears to be a later copy.

In addition to these points, some of the astrolabes feature the head and tail of a dragon on the ends of the circumferential (Capricornian) ring of the rete. The Zuylenburgh astrolabe does not have a properly-modelled head such as found on the AST0590, but it is noticeable that the right-hand termination of the ring is shaped differently to the left one and might possibly be an embryo head (see Fig. 11). Note that the 'species' of the dragon on AST0590 is visibly very different to that on the English 'Chaucerian' astrolabes.[29] Although the inclusion of dragons on the retes of astrolabes appears to have originated in England around 1326, it seems to have passed to Italy soon afterwards.[30]

Discussion – The Stars

Table 2 shows that the stars of the Zuylenburgh astrolabe, as well as those on the two other instruments listed, come from the Kunitzsch VIII table of 49 stars. As it is much smaller than the other two it naturally has a smaller selection of stars with the names more heavily abbreviated but there is a very high degree of overlap in the choices. The one unnamed pointer is easily identified as *Alhaioh* from its position. The positions in both declination and mediation are generally within 2° of the manuscript values and often significantly better (average error $\Delta\mu = 0.31°$, $\Delta\varepsilon = 0.37°$; standard deviations 1.83° an 1.68° respectively). This is about as tight an agreement as can be expected for handmade items which have suffered several centuries of use. There is no evidence of longitude drift indicating that no attempt was made by the makers to allow for the effects of precession – they simply adopted the values in the table.

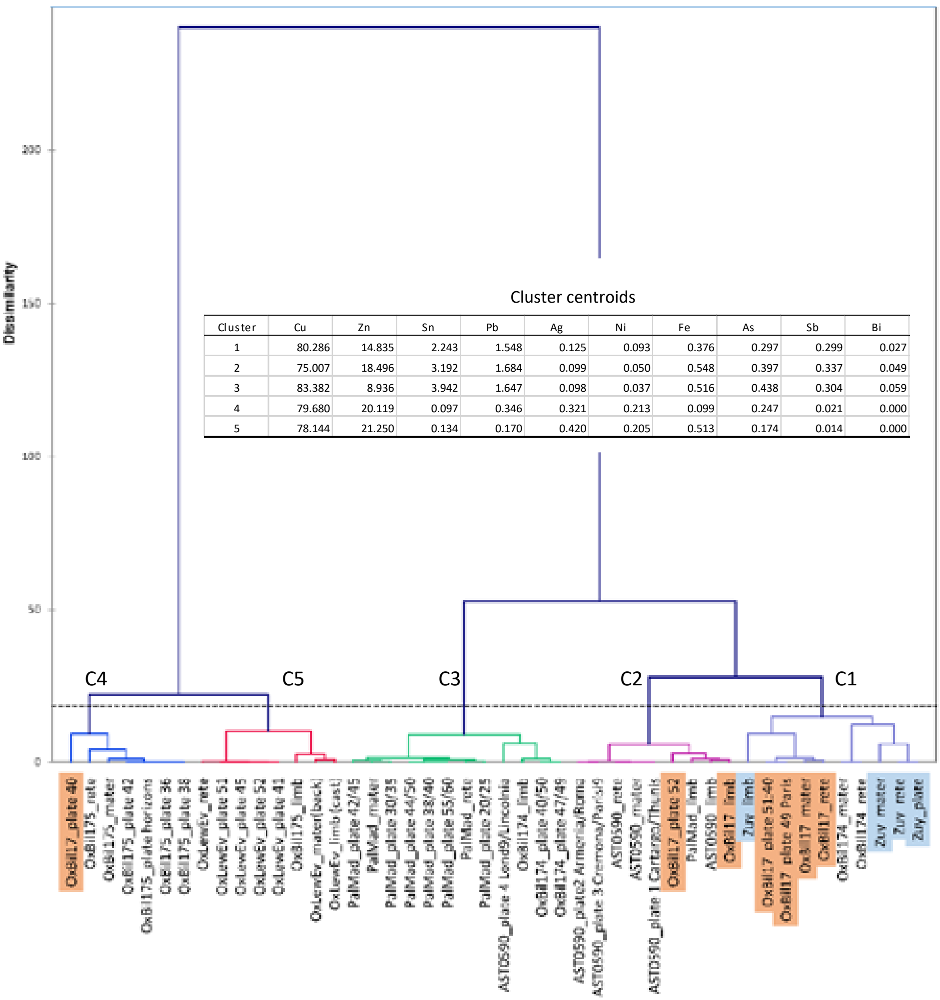
One difference between the Zuylenburgh astrolabe's stars and the other astrolabes is the choice of *Batenkaytoz* rather than the nearby *Mirac*. It is not clear what the significance, if any, there is in this change. It includes neither *Algorab* nor its 'ghost' duplicate *Corvus* which are characteristic of the Type VIII list so it cannot be completely certain that this is the Type that has been used. Similarly, it has an accurate position for the star *Alferaz* whereas several other 'quatrefoil' astrolabes of this period muddle the name and position with those of *Sceder*.[31]

Comparisons with Fusoris Astrolabes and V&A Single Plate Astrolabe

It is instructive to compare the current group of astrolabes with others from northern Europe of around the same period. The only known atelier of the time was that of Jean Fusoris in Paris and this had a significant output over an extended period, including after Fusoris himself had been banished in 1416 to Mézières-sur-Meuse and then died in 1436. Fusoris's astrolabes had a distinct and rather spartan design which nevertheless has some features which could have evolved from the Zuylenburgh group. One such feature is the throne; Fusoris's rather small design is distinguished by a pair of small 'shoulders' or 'pips' either side of the throne which are reminiscent of the barbs on the Zuylenburgh design. The retes on Fusoris astrolabes also have an arc in the upper ecliptic circle though it is often concentric with the ecliptic rather than being an arc of the equatorial circle. The Parisian workshop seems to have employed a number of engravers with recognisably different styles, none of them like the Zuylenburgh engraver nor as proficient.

An astrolabe in the Victoria and Albert (V&A) Museum, London[32], has a number of stylistic similarities to the Zuylenburgh group despite being made as a single-sheet instrument without a removable plate or raised limb. It lacks the 'barbed demi-quatrefoil' throne which is perhaps the principal characteristic of the Zuylenburgh/Tomba group, but it does use an

Fig. 12 *Transmission X-radiograph of the mater of the Zuylenburgh astrolabe showing the season cracking and the internal construction of the throne. Details of the rivets holding the limb to the backplate are also visible. (Radiograph made by AP at the Rijksmuseum, Amsterdam.)*



Cluster	Cu	Zn	Sn	Pb	Ag	Ni	Fe	As	Sb	Bi
1	80.286	14.835	2.243	1.548	0.125	0.093	0.376	0.297	0.299	0.027
2	75.007	18.496	3.192	1.684	0.099	0.050	0.548	0.397	0.337	0.049
3	83.382	8.936	3.942	1.647	0.098	0.037	0.516	0.438	0.304	0.059
4	79.680	20.119	0.097	0.346	0.321	0.213	0.099	0.247	0.021	0.000
5	78.144	21.250	0.134	0.170	0.420	0.205	0.513	0.174	0.014	0.000

Fig. 13 *Dissimilarity dendrogram resulting from the Agglomerative Hierarchical Clustering analysis of the sheet components from seven of the 'Tomba Group' astrolabes, using the 10 characteristic chemical elements. The four components of the Zuylenburgh astrolabe are identified by blue labels; the fawn labels show the seven components of Billmeir 17.*

all-capital lettering style with extensive use of ligatures and omission signs. It is usually ascribed to a French workshop on account of its single latitude of 48° 50′, a standard value for Paris but not the one used on the Zuylenburgh plate. This suggests a different workshop possibly with links to the Tomba group one.

Metallurgy and Materials Analysis

A transmission X-ray image of the Zuylenburgh mater (Fig. 12) was taken clearly showing the intergranular cracking of the backplate, usually starting towards the middle of the plate and sometimes reaching the edges. The rivets holding the annular limb to the backplate can also be seen and it is apparent that they do not always penetrate completely perpendicular to the surface though they have been hammered flat and smoothed off so that this is not immediately clear visually. A similar image of the plate (not shown) also showed cracks although not quite so prominently.

The alloy composition of the components of the Zuylenburgh and NMM AST0590 astrolabes, as well as several other instruments from the group, were analysed by X-ray fluorescence (XRF) – see the Appendix for the method employed. The results are shown in Table 6. They show that all the major components of all the astrolabes are made of a 'latten', a quaternary copper alloy with primary additions of zinc, tin and lead together with low levels of unintentional elements, particularly silver, iron and nickel and smaller amounts of arsenic, antimony and bismuth.

Previous work has shown that components made from hammered sheet provide a better chance of being made from freshly-produced material (and hence characteristic of the source and smelting process) than cast components which have a higher likelihood of containing recycled material. Also, since parts such as alidades, rules and the horse are often replacements, it is better to concentrate on the plates, rete and mater back when making comparisons.

Table 6. Alloy compositions as measured by XRF in wt% for the Zuylenburgh and some other astrolabes of the 'Tomba group'. See Appendix for the measurement and processing conditions. Measurements by JD unless otherwise stated. The bottom row gives the 'typical' error for the element as calculated by the PyMCA routine (see note 41)

Astrolabe	CCL/IIL	Part	Cu	Zn	Sn	Pb	Ag	Ni	Fe	As	Sb	Bi	Comment
1. Zuylenburg Measurements by AP	–	mater	74.6	22.0	1.40	0.83	0.13	0.06	0.35	0.21	0.33	0.01	
		limb	81.6	12.2	2.34	1.76	0.22	0.04	0.63	0.48	0.59	0.06	
		rete	81.3	16.3	0.95	0.46	0.12	0.03	0.22	0.31	0.21	0.04	
		plate	81.6	16.1	0.93	0.42	0.10	0.03	0.21	0.32	0.20	0.04	
2. NMM AST0590	#3059	mater	75.5	17.8	3.49	1.93	0.10	0.05	0.46	0.41	0.33	0.05	
		limb	73.7	20.4	2.97	1.29	0.08	0.03	0.63	0.39	0.31	0.05	
		rete	75.1	17.5	3.75	1.81	0.09	0.05	0.49	0.43	0.35	0.06	
		plate 1 Cartargo/Thunis	75.4	17.7	3.60	1.99	0.10	0.05	0.44	0.39	0.34	0.06	
		plate2 Armenia/Roma	74.3	18.9	3.48	2.06	0.10	0.05	0.44	0.40	0.35	0.06	
		plate 3 Cremona/Parisi[9]	74.5	18.8	3.40	2.03	0.10	0.05	0.44	0.36	0.33	0.06	
		plate 4 Lond[9]/Lincolnia	87.1	5.89	4.10	1.72	0.12	0.05	0.19	0.61	0.32	0.09	different workshop
		alidade	73.6	21.5	2.59	1.23	0.09	0.03	0.48	0.39	0.29	0.06	
		rule	67.7	31.1	1.12	1.12	0.09	0.01	0.01	0.01	0.01	0.00	
		shackle	74.1	20.9	2.50	1.26	0.13	0.03	0.77	0.29	0.50	0.04	
3. Palazza Madama 0922/b (Tomba A) Measurements by AA	#3203	mater	82.6	9.70	3.98	1.29	0.08	0.03	0.61	0.42	0.27	0.05	
		limb	76.6	16.4	2.85	1.54	0.13	0.03	0.48	0.43	0.33	0.03	
		rete	82.4	10.6	3.62	1.08	0.09	0.03	0.46	0.48	0.28	0.04	
		plate 20/25	83.3	9.40	3.71	1.24	0.09	0.03	0.53	0.44	0.30	0.03	
		plate 30/35	81.9	10.2	4.07	1.23	0.09	0.03	0.69	0.43	0.27	0.07	
		plate 38/40	83.0	9.50	3.94	1.32	0.09	0.04	0.47	0.41	0.27	0.06	
		plate 42/45	82.1	9.90	3.59	1.83	0.10	0.03	0.59	0.38	0.32	0.05	different hand
		plate 44/50	82.9	9.60	3.83	1.29	0.08	0.02	0.48	0.40	0.30	0.06	
		plate 55/60	82.9	9.50	3.89	1.31	0.09	0.03	0.48	0.44	0.27	0.06	
		alidade	80.4	11.9	3.79	1.67	0.13	0.05	0.27	0.56	0.31	0.05	
		rule	80.4	17.6	0.02	0.52	0.02	0.18	0.06	0.04	0.02	0.00	modern?
		pin	79.8	8.80	3.41	3.93	0.80	0.12	0.13	0.12	0.07	0.00	
6. OxHSM 54330 Billmeir 17	#410	mater	80.9	12.8	3.24	1.99	0.12	0.05	0.38	0.34	0.39	0.01	
		limb	75.7	17.2	3.65	1.24	0.08	0.09	0.68	0.43	0.32	0.03	
		rete	80.8	12.7	3.42	1.13	0.08	0.07	0.39	0.34	0.42	0.01	
		plate 51;40	81.5	12.1	3.68	1.73	0.14	0.11	0.35	0.32	0.30	0.03	
		plate 52	74.1	21.8	1.54	1.27	0.11	0.05	0.87	0.34	0.37	0.04	
		plate 40	80.2	19.2	0.00	1.19	0.04	0.31	0.09	0.09	0.07	0.00	
		plate 49 Paris	81.3	12.0	3.87	1.87	0.16	0.11	0.36	0.29	0.31	0.02	
		alidade	76.5	23.0	0.00	1.49	0.02	0.03	0.08	0.01	0.01	0.00	
		pin	80.7	13.4	1.78	1.51	0.09	0.19	0.75	0.16	0.17	0.00	
		horse	69.2	31.2	0.00	0.32	0.00	0.00	0.03	0.02	0.01	0.00	modern

Astrolabe	CCL/IIL	Part	Cu	Zn	Sn	Pb	Ag	Ni	Fe	As	Sb	Bi	Comment
7.OxHSM 47615 Billmeir 175	#2043	mater	78.1	22.0	0.00	0.24	0.45	0.17	0.14	0.16	0.01	0.00	
		limb	79.9	19.0	0.09	0.22	0.40	0.22	0.71	0.46	0.02	0.00	
		rete	82.3	17.4	0.10	0.23	0.36	0.25	0.17	0.46	0.01	0.00	
		plate 42	79.7	20.2	0.14	0.19	0.38	0.19	0.08	0.25	0.01	0.00	
		plate horizons	79.4	20.5	0.14	0.18	0.34	0.19	0.07	0.25	0.01	0.00	
		plate 36	79.1	20.7	0.15	0.19	0.33	0.19	0.07	0.26	0.02	0.00	
		plate 38	79.1	20.8	0.15	0.20	0.35	0.19	0.07	0.26	0.02	0.00	
		alidade	74.0	24.9	0.54	0.35	0.34	0.22	0.13	0.47	0.02	0.00	
		pin	76.7	17.6	2.12	2.02	0.06	0.17	0.53	0.17	0.36	0.00	
		horse	60.3	38.3	0.10	0.72	0.00	0.07	0.09	0.03	0.05	0.00	modern
8.OxHSM 36338 Billmeir 174	#2042	mater	79.5	16.1	1.28	2.79	0.09	0.01	0.44	0.18	0.12	0.03	
		limb	82.5	8.0	4.59	2.59	0.11	0.06	0.62	0.49	0.41	0.07	
		rete	79.7	16.1	1.25	2.50	0.09	0.01	0.43	0.18	0.12	0.02	
		plate 40/50	85.0	7.51	3.99	2.29	0.12	0.05	0.54	0.39	0.32	0.07	
		plate 47/49	84.8	7.42	4.00	2.58	0.12	0.05	0.54	0.38	0.32	0.07	
		alidade	79.7	11.3	3.94	2.90	0.12	0.05	0.76	0.43	0.34	0.06	
		rule	82.7	10.5	3.65	1.52	0.07	0.08	0.33	0.34	0.35	0.09	
		pin	59.9	38.4	0.35	2.12	0.01	0.04	0.15	0.01	0.01	0.00	modern
9.OxHMS 41468 Lewis Evans 21/2063	#168	mater (back)	79.5	19.2	0.56	0.23	0.43	0.22	0.47	0.30	0.02	0.00	
		limb (cast)	79.8	19.2	0.41	0.08	0.24	0.23	0.47	0.23	0.02	0.00	
		rete	78.4	21.3	0.00	0.14	0.45	0.20	0.48	0.09	0.01	0.00	
		plate 52	77.0	22.7	0.00	0.15	0.45	0.20	0.50	0.07	0.01	0.00	
		plate 51	76.8	22.8	0.00	0.19	0.48	0.19	0.50	0.08	0.01	0.00	
		plate 41	77.0	22.8	0.01	0.17	0.41	0.19	0.49	0.08	0.01	0.00	
		plate 45	76.7	23.0	0.00	0.18	0.50	0.19	0.48	0.08	0.01	0.00	
		alidade	74.3	23.0	1.18	1.31	0.08	0.03	0.18	0.37	0.07	0.12	
		rule	75.3	22.2	1.15	1.26	0.08	0.03	0.19	0.36	0.06	0.12	
		pin	70.3	29.6	0.00	0.39	0.00	0.27	0.12	0.05	0.04	0.00	modern
Typical 95% confidence band			±2.7	±0.2	±0.2	±0.2	±0.02	±0.05	±0.04	±0.08	±0.07	±0.04	

Fig. 14 *Front of the astrolabe Billmeir 17 (now Oxford HMS 54330; #410). Photo courtesy of the History of Science Museum, University of Oxford. Notice the engraved numeral '4' on the throne, just possibly indicating the number in a batch of similar instruments.*

It is not possible to date metal alloys scientifically and methods for the full analysis of complex alloys of this type are still under development. As a general comment, it is possible to say that the zinc levels of latten in the late medieval period tend to rise and the tin levels decrease steadily with time. The levels of impurities observed in the Zuylenburgh, NMM AST0590, Billmeir 174 and parts of Billmeir 17 astrolabes correspond with copper from the Rammelsberg, in the Harz mountains. Until the mid-14th century, this was one of the most prominent sources of copper in Europe, supplying both important staple markets, such as Hamburg, Lübeck and Bruges, and a thriving local brass industry. A chemical study of several 12–13th century copper-alloy monuments in the nearby towns of Goslar and Braunschweig provides a reference to the chemical composition of this type of copper, which shows consistent levels of nickel below 0.1%, silver around 0.1%, roughly equal amounts of arsenic and antimony varying between 0.1 and 0.6% and usually a trace of bismuth.[33] The Lewis Evans astrolabe 21/2063 (#168) and Billmeir 175 chemically resemble several mid- 15th century brass funeral monuments from Saxony and Thuringia and are thus more probably from the 15th century.[34]

The dendrogram of Fig. 13 shows the calculated dissimilarities of the alloys comprising the maters, limbs, retes and plates of the seven 'Tomba group' astrolabes for which data were available, using the 10 analyte elements. The components of the Zuylenburgh astrolabe are highlighted by blue labels and can be seen to lie quite closely grouped in 'Cluster 1' on the right hand side of the diagram. The line for its limb is slightly separated, possibly because a different alloy has been selected due to its thickness. The astrolabe which is most similar to the Zuylenburgh one, with components highlighted by brown labels, is clearly that originally known as Billmeir 17 (HMS inv. 54330, #410[35]). This is shown in Fig. 14 and, visually, it is also the Tomba group astrolabe most similar to the Zuylenburgh one as it is a relatively simple design without quatrefoils or a dragon and is also relatively small. Together, these results provide good evidence for the existence of a workshop producing a range of astrolabes in different sizes and an evolving design over a period of some years.

Most of the components of AST0590 which, though much larger than the Zuylenburgh instrument, shows comparable palaeography, lie in the adjacent Cluster 2. Note that the retes of the three astrolabes which have breaks in the solstitial bars – Zuylenburgh, AST0590 and Billmeir 17 – all lie in the closely-similar Clusters 1 and 2 thus suggesting that the fragility is due to materials properties.

As an aside, note that the plate for 38°/40° from Billmeir 17 lies on the left hand side of the diagram (Cluster 4) and is thus quite dissimilar to the alloy for the plates of other latitudes in the same set. Close visual inspection shows it to be by a different but contemporary hand, being the only one to have lines for the prime vertical and not to have construction arcs on the equatorial circle. This cluster also contains the components of two other astrolabes now in the Oxford HSM; one from the Lewis Evans collection (#168) which is thought – by Tomba and others – to be a later copy of the main Tomba group.

Similarly, the 'English' plate for Lincoln/London from the astrolabe AST0590 is seen to be a completely different type of alloy (Cluster 3) to the rest of the instrument despite being roughly contemporary.

The Zuylenburgh astrolabe has evidence in several places that the engraving was originally at least partially filled with red wax. Small-spot XRF analysis of these areas[36] showed an excess of lead, Pb, which almost certainly indicates that the colouring pigment was red lead, Pb_3O_4. The alternative red pigment at this period was the more expensive cinnabar (sometimes also known as vermillion) which is HgS but no mercury nor sulphur was detected. This is in contrast to an astrolabe quadrant of *c*. 1300[37] which had alternate red and black wax fills to its engraving where the red was primarily red lead but with a significant component of cinnabar. (The black pigment was identified as 'bone black'.[38]) Relatively few instruments of this period have retained their wax fills, but it is possible that further studies will reveal more details about the workshop practices of the time.

Final Considerations and Conclusions

The Zuylenburgh astrolabe is an important find and adds significantly to the evidence that there was an astrolabe workshop making instruments of high quality in a wide range of sizes and that the astrolabes of the 'Tomba group' are associated with it. Whilst the core astronomical and constructional details remain constant, there is enough variety in the artistic style to suggest that the workshop existed for a significant period and was influenced by other centres such as that in England responsible for the 'royal' or 'Sloane' group where many of the 'Gothic' or quatrefoil features first became prominent on Latin astrolabes.[39] In turn, the Tomba group may have influenced the later output of the Fusoris workshop in Paris. The exact location of the Tomba group workshop remains to be determined but a city state in northern Italy is the most likely. Its working period is only loosely determined but the second half of the fourteenth century, after the Black Death (1347–51), is the most probable.

APPENDIX – XRF Measurement and Analysis Procedure

a) Measurement. X-ray fluorescence spectra of the Zuylenburgh astrolabe were acquired (by AP) using an Olympus Delta X Professional instrument at the Rijksmuseum, Amsterdam. It used a Rhodium anode at 50 kV and a 2 mm Al filter with an 8 mm spot size. All other spectra were acquired with one of two Thermo-Scientific Niton XL3t GOLDD^{++} analysers. They had X-ray tubes with an Ag anode and were generally operated at 40 kV. The Palazzo Madama astrolabe was analysed (by AA) in Turin and all the astrolabes in English museums by JD.

All the instruments had energy dispersive silicon drift detectors with thermo-electric cooling. The astrolabe components were not specially cleaned before analysis but note that AST0590 had a polished appearance. Flat areas with as little engraving within the 8 mm diameter analysed spot were chosen wherever possible. Each value in Table 6 is the average of several analyses in different areas of each component, where possible from both sides of sheet components. For separate analyses (not shown) for investigating the patina/corrosion on the Zuylenburgh astrolabe, the analyser was operated at a lower voltage of 6 kV.

b) Spectrum processing. Although the Niton analysers had an internal algorithm which had been calibrated against the full set of the copper CHARM (Cultural Heritage Alloy Reference Material) set of Certified Reference Materials[40] for extracting alloy compositions from the spectra in real time, this was only used for an initial check on the results. The Olympus Delta X had similar internal algorithms. However, for the all values (in weight %) reported in Table 6, the raw spectra were exported for batch processing offline using the 'Charmed PyMCA' protocol.[41] This uses an open-source Fundamental Parameters analysis routine using the characteristics of the analyser but then adjusted using previously-obtained results from the CHARM CRMs. This protocol has been shown to produce consistent results across a range of different manufacturers of portable XRF analysers operated over a number of museum laboratories worldwide. The typical error band for each of the analyte elements was remarkably consistent across the three analysers and is shown in the final line of Table 6. The FP spectrum-fitting method has been shown to be more accurate for extracting results from low-levels of arsenic, As, in the presence of lead, Pb (which have overlapping and unresolvable main spectral peaks). It can also assess problems caused by non-ideal surface conditions by monitoring both the high energy (K_α, 25.27 keV) and low energy (L_α, 3.44 keV) peaks for tin, Sn.

c) Data analysis. The 10 analyte elements selected as representative of each alloy were Cu, Zn, Sn, Pb, Ag, Ni, Fe, As, Sb and Bi; the first four are to some extent under the control of the smelter and the other six unintentional impurities are approximately in order of their importance. Although there are many methods of interpreting the compositions of copper-alloys[42], the method employed here concentrated on a form of agglomerative hierarchical clustering (AHC)[43] which, although now a rather old technique for multivariate statistical analysis, has advantages in that its visual outputs can be more readily understood in engineering terms than other methods such as Principal Component Analysis. The method has previously been used, for example, to classify prehistoric copper alloys.[44] The processing was performed using the commercial XLSTAT program[45], using all 10 of the analyte elements on a linear scale with no weighting (it was felt that the importance of each element tended to be reflected by its concentration) and using Euclidean distances with Ward's method. The results are displayed as dissimilarities. Many other options for the processing exist, including the normalisation of the analyte components, possible exclusion of the copper component as it forms 'the remainder' of the alloy after the additions, and different choices for the clustering calculations. Exploration of these options is part of an ongoing programme which may eventually provide information on the sources of metals used by the instrument-making workshops.

Acknowledgements

We are grateful to Louise Devoy (National Maritime Museum) and the private owner for access to AST0590. Arlen Heginbotham (J. Paul Getty Museum) was extremely helpful with providing the Charmed PyMCA procedure and further support. Domenico Inaudi (Turin Polytechnic) and Giancarlo Truffa (independent historian, Milan) were of great help in studying the astrolabes now in Turin and Milan. Silke Ackermann and Lucy Blaxland (History of Science Museum, University of Oxford) are thanked for access to the 'Italian' astrolabes there. Tiziana Caserta, curator of the Civic Museum of Ancient Art of Turin, is thanked for providing access to the Palazzo Madama astrolabe and Anthony Turner (Paris) helped in tracing several astrolabes. Paulo Brenni kindly provided copies of a number of articles.

Authors' Affiliations

1.Independent researcher
2. Collection Zulenburgh Planetarium
3. Independent researcher
4. Department of Mathematics, Utrecht University
5. Conservation and Science Department, Rijksmuseum, Amsterdam
6. Department of Chemistry, University of Turin

Notes and References

1. Emmanuel Poulle, *Un constructeur d'instruments astronomiques au XVe siècle Jean Fusoris* (Paris: Librairie Champion, 1963).

2. Details of the Zuylenburgh collection can be found at http://planetariumzuylenburgh.com/en/

3. J. Davis and M. Lowne, 'An Early English Astrolabe at Gonville & Caius College, Cambridge, and Walter of Elveden's *Kalendarium*'. *J. History Astronomy,* **46** (3), pp. 257–290, (August 2015). DOI: 10.1177/0021828615590336.

4. A. R. Bailey, 'The Stress-Cracking Of Brass', *Journal Metallurgical Reviews*, **6** (1), (1961), pp. 101-141. https://doi.org/10.1179/mtlr.1961.6.1.101/.

5. An astrolabic quadrant with alternate red and black infills used to differentiate the folded quadrants is described in E. Dekker, 'An Unrecorded Medieval Astrolabe Quadrant from c. 1300', *Annals of Science*, **95** (1995), pp. 1-47. A case for coloured infills on the Sloane astrolabe is advanced in J. Davis, 'Fit for a King. Decoding the great Sloane astrolabe and other English astrolabes with

“quatrefoil” retes’, Chapter 9 (pp. 310-56) in *Astrolabes in Medieval Cultures*, Josefina Rodriguez-Arribas, Charles Burnett, Silke Ackermann and Ryan Szpiech, eds, (Leiden: Brill, 2019). DOI:10.1163/9789004387867.

6. Paul Kunitzsch, *Typen von Sternverzeichnissen in astronomischen Handschriften des zehnten bis vierzehnten Jahrhunderts* (Wiesbaden, 1966).

7. The many manuscript versions of the pseudo-Messahalla star table have been edited by Ron B. Thompson, ‘*Pseudo-Masha’allah – On the Astrolabe*, available by download from https://shareok.org/handle/11244/14221/

8. All measurements of engraved features on the astrolabe were made by importing high resolution photographs of the components, taken with a long focal distance macro lens and with the camera plane precisely parallel to the astrolabe surface, into a CAD system. This allowed the features to be reverse-engineered, providing a check on the circularity of the circles and the perpendicularity of the principal diameters.

9. For example, the Great Sloane astrolabe in the British Museum, and the Museum’s dated 1326 astrolabe, both use 24° as the obliquity, thought to be derived from the Toledan Tables.

10. Calculated from the position and radius of the horizon circle.

11. For the relevant equations and examples from other, contemporary, astrolabes, see J. Davis, ‘The “Chaucerian” Astrolabe in the British Museum: A Reassessment of Its Dating and Ownership’, *Journal for the History of Astronomy*, **50** (2) (May 2019), pp. 121-154. DOI: https://doi.org/10.1177/0021828619845585/

12. A listing of the azimuth spacings on a number of astrolabes is given in Davis, ‘Chaucerian astrolabe’ (see note 11).

13. J. Davis: ‘Dating an astrolabe from its calendar scales’, *Bulletin of the Scientific Instrument Society*, No. 135 (December 2017), pp. 2–7.

14. See Poulle (note 1), p. 107.

15. Davis & Lowne (note 3).

16. See Thompson, *On the Astrolabe* (note 7). The Calendar table is in Part VI-5, Addendum 2-2.

17. The unfinished Frankfurt Catalogue of Medieval Instruments in a revised form has most recently been published as David A. King, ‘European Astrolabes to *ca*. 1500: An Ordered List’, in *Astrolabes in Medieval Cultures*, Josefina Rodriguez-Arribas, Charles Burnett, Silke Ackermann and Ryan Szpiech, eds (Leiden: Brill, 2019). DOI:10.1163/9789004387867. David King’s unpublished notes of both astrolabes are available for download from https://uni-frankfurt.academia.edu/DavidAKing/

18. NMM AST0590 is previously unpublished: it is listed in the Frankfurt IIL as #3058. The Milan astrolabe #4516 was previously in the collection of Tullio Tomba and a basic description is in Tullio Tomba and Giuseppe Brusa, *Museo D’Arti Applicate: Strumenti Scientifici-Orologi*, (Milan: Electra Editrice, 1983), p. 20 & plates 32-34 where it is designated mid-14th century and Italian. It also appears in Tullio Tomba, ‘Tre Astrolabi Latini, del XIV Secolo, Conservati in Italia’, *Rassegna di Studi e di Notizie*, XX, Anno XXII (= 1996; unpaginated reprint).

19. Tullio Tomba, ‘Tre Astrolabi Latini, del XIV Secolo, Conservati in Italia’, *Esstratto da: Rassegna di Studi e di Notiziee*, Volume XX – Anno XXII. (Milan) Unpaginated, undated.

20. Tomba A and B and Ox 47615 & 543300. See Anon., *A Catalogue of Scientific Instruments from the 13th to the 19th centuries from the collection of J.A. Billmeir, CBE*, and *Supplement* (Oxford: Chiswick Press, 1957). The Billmeir collection of astrolabes had been purchased complete from the French collector Henri Michel but their earlier provenance is unknown.

21. The astrolabe was lot 124 in the Sotheby’s auction held in London on 18 June 1986. Its present location is unknown although its rete has recently been shown in D. & E. Delalande and Patrick Rocca, *Astrolabes Vol. I*, (Paris, 2020), p. 251. The catalogue description and photographs show it to have been later modified for practical use, probably in Renaissance Italy. The stars, engraved in an all-capital Lombardic style, closely match those of the other ‘Tomba’ astrolabes and it has the ‘barbed demi-quatrefoil’ throne which characterises the group.

22. For a brief account of Tomba’s career, see Mara Miniati, ‘The Collecting Taste: Italian Case-studies between the Nineteenth and Twentieth Centuries’, in Strano, Johnston, Miniata & Morrison-Low, eds., *European Collections of Scientific Instruments, 1550-1750*, (Leiden: Brill, 2009), pp. 191-204.

23. Gerard L’E Turner, *Strumenti Scientifici Del Rinascimento Italiano (Italian Renaissance Scientific Instruments)*, Collezione Koelliker; 2005, pp. 34-37. It is described there as ‘XV century’.

24. T. Tomba, ‘Due Astrolabi Latini Del XIV Secolo Conservati a Milano (Two Latin astrolabes of the fourteenth century preserved in Milan)’, *Physis*, **8** (3) (1966), pp. 295-306.

25. Emmanuel Poulle, ‘Remarques sur deux astrolabes du moyen âge (Remarks on two astrolabes of the Middle Ages)’, *Physis*, **9** (1967), pp. 161-164. The academic Poulle was good on manuscripts but seems to have lacked ‘feel’ for the style of real instruments.

26. T. Tomba, ‘Nuove Observazione sui due Astrolabi Latini Del XIV Secolo Conservati A Milano (New observations on the two Latin astrolabes of the fourteenth century preserved in Milan)’, *Physis*, **10** (2) (1968), pp. 119-122.

27. Adriano Cappelli (author), David Heimann & Richard Kay (trans.), *The Elements of Abbreviation in Medieval Latin Paleography*, (Lawrence: U. Kansas Publications, 1982).

28. For a discussion on the use of the Capricorn marker, see Anthony Turner, ‘Concerning a Pointer on the Astrolabe’, *J. History Astron*., **46** (4), (2015), pp. 413-418.

29. J. Davis, ‘The “Chaucerian” Astrolabe (note 11).

30. J. Davis, ‘Hic sunt dracones. Why are there dragons on medieval astrolabes?’, *Bulletin of the Scientific Instrument Society* No. 143 (December 2019), pp. 2–12.

31. An example is given in J. Davis: ‘A Royal English Medieval Astrolabe Made for Use in Northern Italy’, *J. Hist. Astron.,* **48** (1) (Feb. 2017), pp. 3–32. DOI: 177/0021828616681214.

32. The V&A astrolabe is inv. M.128-1923 (#190). It is 229 mm in diameter and can be seen at http://collections.vam.ac.uk/item/O375766/astrolabe/

33. G. Laub, ‘Zum Nachweis von Rammelsberger Kupfer in Kunstgegenständen aus Goslar und in anderen Metallarbeiten des Mittelalters’, *Bergstadt-Kaiserstadt in Geschichte und Kunst. Bericht über ein wissenschaftliches Symposion in Goslar vom 5. bis 8. Oktober*. (Göttingen, Goltze, 1993), pp. 303-311.

34. P. Bellendorf, ‘Metallene Grabplatten aus Franken und Thüringen aus dem 15. bis 18. Jahrhundert eine interdisziplinäre Studie zum Denkmalbestand und seiner Gefährdung durch Umwelteinflüsse’, (Otto-Friedrich-Universität, 2008), p. 172; J. Riederer, ‘Metallanalyse der Messinggrabplatten im Meißner Dom’. *Die Grabmonumente im Dom zu Meissen*, by M. Donath, (Leipziger Universitätsverlag, 2004), pp. 112-124.

35. Oxford HMS 54330 (Bilmeir 17; #410) can be seen online at https://www.mhs.ox.ac.uk/astrolabe/catalogue/browseReport/Astrolabe_ID=250.html/

36. The measurements were made by AP at the Rijksmuseum, Amsterdam, using a Bruker Artax system with a Mo anode at 40 kV and

using a poly-capillary lens to give a 60 micron spot size.

37. The quadrant, which has previously been published as Elly Dekker, 'An Unrecorded Medieval Astrolabe Quadrant from c.1300', *Annals of Science*, **52** (1995), pp.1-47, was sold at auction in December 2019, see https://www.christies.com/lotfinder/Lot/a-highly-important-medieval-astrolabe-quadrant-probably-6245170-details.aspx/

38. The black pigment was almost certainly mainly carbon which is invisible to XRF. However, the source could be identified as 'bone black' – burnt and crushed animal bones – by the presence of calcium and phosphorous coming from the calcium phosphate, $Ca_3(PO_4)_2$ and calcium carbonate, $CaCO_3$ within the bone.

39. J. Davis, 'An Early-Fourteenth-Century English Astrolabe in Milan and Contemporary Anglo-Italian Politics', In preparation.

40. A. Heginbotham, J. Bassett, D. Bourgarit, C. Eveleigh, L. Glinsman, D. Hook, D. Smith, R.J. Speakman, A. Shugar and R. van Langh, 'The Copper CHARM Set: a New Set of Certified Reference Materials for the Standardization of Quantitative X-ray Fluorescence Analysis of Heritage Copper Alloys', *Archaeometry*, DOI: 10.1111/arcm.12117 (2014).

41. A. Heginbotham and V. A. Solé, 'Charmed Pymca, Part I: A Protocol for Improved Inter-Laboratory Reproducibility in the Quantitative ED-XRF Analysis of Copper Alloys', *Archaeometry*, **59** (4) (2017), pp. 714–730. Also A. Heginbotham et al, 'CHARMed PyMca Part II: An Evaluation of Interlaboratory Reproducibility for ED-XRF analysis of Copper Alloys', (October 2018).

42. For a recent survey of methods see A.M. Pollard et al, *Beyond Provenance. New approaches to interpreting the chemistry of archaeological copper alloys*, (Leuven: Leuven University Press, 2018).

43. For an introduction to clustering, see H. Charles Romesburg, *Cluster Analysis for Researchers*, (Wadsworth, 1989).

44. Roland Müller and Ernst Pernicka, 'Chemical Analyses in Archaeometallurgy: A View on the Iberian Peninsula', in *Metals and Societies. Studies in honour of Barbara S. Ottaway*, Tobias L. Kienlin & Ben W. Roberts, eds, (Bonn: Dr Rudolf Habelt, 2009), pp. 296-306.

45. Addinsoft (2020). https://www.xlstat.com/

Correspondence to be directed to:
john.davis51@btopenworld.com

Book Review

Opinions expressed by reviewers are their own opinion, and do not necessarily reflect the views of the Society. The review continues on p. 33.

Innovation in the Design of Scientific Instruments in the Georgian Era: the role of the Society of Arts

D.J. Bryden
Published by the William Shipley Group for RSA History
WSG Research Paper 3, 2019
Softback, 238 pages, illustrated
ISBN: 978-0-244-20311-5
Price £17.50 + £2.00p&p Publisher: WSG Gallery (2019)

Available from the Honorary Secretary, William Shipley Group for RSA History, 47 Barringers Court, Neats Acre, HA4 7JP or email: susan@bennett.as.

A question of considerable interest to economists and historians of technology alike is whether patents or prizes offer the greater spur to invention, and which provides the greater benefit to the wider economy. By the late eighteenth century, Great Britain had already been granting monopolistic rights in the form of patents in small numbers for several decades prior to that famously awarded to Boulton and Watt in 1796 for their steam engine, but the process was costly and fraught with difficulty. The French and American Revolutions of only a few years earlier provided both countries with a *tabula rasa* on which to create their own, more rationalized patent systems. Before that, however, neither country had a patent system at all. And the patent system in Germany did not arrive until after German unification in 1871.

On the other hand, the French *Académie des Sciences* had already been awarding medals and financial prizes for practical innovations since as early as 1721, but without any monopolistic rights attached to them. Early winners often offered solutions to the prevailing problems of maritime navigation, included Coulomb, who in 1777 was awarded a prize for a *mémoire* on the magnetic compass. By the early nineteenth century, prize winners included some of the greatest names in science: Fourier, Fresnel and Poisson, to name but a few. In Britain meanwhile, the Society for the Encouragement of Arts, Manufactures and Commerce founded by William Shipley (later called the Royal Society of Arts) began to offer prizes in the form of medals and financial premiums, with the specific stipulation that they would *not* be awarded for patented inventions.

After having published a series of articles in the *SIS Bulletin* on historical patents for scientific instruments, the author of the work now under review has turned his attention to the prizes and premiums awarded by the Royal Society of Arts for designs for scientific instruments. The result is a reference work which is not really a book as such, but more of a monograph, and although it has an ISBN, you will be hard-pressed to find it in any bookshop, either in the high street or online. The title page describes it as 'WSG Research Paper 3'. The WSG is the William Shipley Group for RSA History, which is independent of the present-day Royal Society of Arts but dedicated to researching the RSA's history. A copy of this reference work can therefore best be obtained from the WSG itself.

Indeed, this work has some serious shortcomings as a book. Although it has been printed double-sided, all the page numbers are inconveniently placed in the bottom right-hand corner, regardless of whether the page is *recto* or *verso*. The margins of the *recto* and *verso* pages are also the same as each other, so that the text on the *verso* sides is too uncomfortably close to the spine to be read with ease. The contents page is less than useless, as it contains no page numbers! I tried to fill these in myself with a pencil, but was defeated, since the 'Introduction' and 'Essay', which are successively listed in the contents, merge seamlessly into each other, so that it is impossible to determine where one ends and the other begins.

The contents page notwithstanding, the work comprises a 41-page introductory essay, followed by four Appendices (eccentrically numbered as 1, 2, 3 and 3a), which together occupy a more substantial 190 pages. The introductory essay contains some paragraphs stretching over more than 1000 words each. One paragraph bridging pages 27 to 29 covers nearly two whole sides of the work's A4 format! Quite apart from the grammatical principle that a single paragraph should treat a single topic, this is very wearing on the eye. Some individual sentences also extend over more than 100 words each and include numerous sub-clauses, so although grammatical, their point is lost. The point of two boxes on the American inventor Jacob Perkins, which are tacked onto the end of the introductory essay, is completely elusive, since their contents bear no relation to the preceding text.

The best that can be said of all this is that the production of this work has been somewhat amateurish. The sad thing is that these niggles could easily have been sorted out in a day or two spent at home on a laptop computer, using nothing more sophisticated than Microsoft Word.

Continued on page 33