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DATING A LATIN ASTROLABE

Emmanuel Davoust
IRAP and Heritage Commission, Observatoire Midi-Pyrénées,
14 Avenue Belin, F-31400 Toulouse, France.
E-mail: manu.davoust@free.fr

Abstract: We have determined the most probable date for the catalog of 34 stars that was used in the construction of a Latin astrolabe originally owned by the Dominican preacher friars and presently in the Musée des Arts Précieux Paul-Dupuy in Toulouse, France. To this end we digitized a photograph of the rete and the rule of the astrolabe, computed the equatorial coordinates of the ends of the 34 star pointers of the rete, and produced a list of 113 reference stars taken from several lists of stars on astrolabes. We then compared the coordinates of the ends of the pointers and those of the reference stars for dates between 1400 and 1700. The most probable date for this astrolabe is 1550.

Keywords: French astrolabe, astronomical instrument, Musée des Arts Précieux Paul-Dupuy

1 INTRODUCTION

The astrolabe is an instrument for making astronomical observations and solving many astronomy problems (Hayton, 2012; Hoskin, 1999; North, 1974). It is an instrument with a long history. The stereographic projection was first discussed by Hipparchus of Nicaea and used in the theory of the planispheric astrolabe written by Claudius Ptolemy two centuries later (Gibbs and Saliba, 1984, and references therein), which is based on a double stereographic projection.

The first astrolabe was produced in the Greco-Roman world, perhaps in the fourth century. Treatises of the astrolabe in Arabic became common in the eighth century and Arabic astrolabes were built by astronomers and engineers of the Abbassid Caliphate, mainly in Syria, and spread East to India and West to Muslim Spain.

The diffusion of the astrolabe in Christian Europe dates from the late tenth century when Arabic treatises on the astrolabe were translated into Latin, probably with the encouragement of Gerbert of Aurillac, the future pope Sylvester II. The first Latin astrolabes date from the thirteenth century (Poulle, 1972). Before that, astrolabes were imported from Muslim Spain. In the Middle Ages, it was the most widely used astronomical instrument, for astronomical observations, but also for other purposes, such as teaching at the university. For example, the Sloane astrolabe in the British Museum was used as a teaching tool for the future King Edward III of England (Davis, 2019). The astrolabe was also treasured for its esthetic value, which may have contributed to its popularity.

The astrolabe was progressively replaced around 1700 by the sextant and the theodolite, which were more precise, but lacked abacuses for performing calculations.

2 DESCRIPTION OF THE ASTROLABE

The astrolabe discussed in this paper (Figures 1 and 2) is made of bronze. It has a diameter of 11.5 cm and a thickness of 0.8 cm. It is composed of a mater, an alidade, a rete, a rule and seven plates. It is joined to a ring by a throne decorated with a five-petal flower.

The mater is a disc, on the back of which graduations allow you to determine the height of stars above the horizon and the position of the Sun in the sky for each day of the year using the alidade. On the back is the inscription “Cont. Tolos. Ord. F.F.P.P.”, which stands for *Conventus Tolosanus Ordinis Fratrum Predicatorum*. This inscription must have been added in the seventeenth century, judging from the cursive script. Above the inscription is engraved a round seal, that of the Dominican preacher friars (see Figure 3). On the front of the mater are successively mounted the plate, the rete and the rule.

The plate is a disk on which curved lines are engraved allowing the altitudes of stars to be converted into hours. As the layout of these lines depends on the latitude of the location of the observer, it is necessary to have a plate for each observation latitude. The present astrolabe has seven plates of silvered bronze, 10.7 cm in diameter. Each face of the plates corresponds to a latitude, which is engraved under the line of the horizon. The 14 latitudes are 24°–32°, 38°–42°, 45°–46°, 47°–48°, 49°–50°, 51°–53° and 56°–60°. On each face are drawn numbered lines corresponding to the Regiomontanus astrological houses. The line of twilight and dawn is also drawn, which is rather uncommon.

The rete represents a planar projection of the celestial sphere, with the pole star at its center. It is a cut-out disk comprising:

- A graduated ring (representing the ecliptic circle) on which the names of the twelve con-

Figure 1: The front of the astrolabe, with a plate, the rete, the alidade (diagonal bar), the rule (vertical bar) (photograph: Jacques Cadaugade).

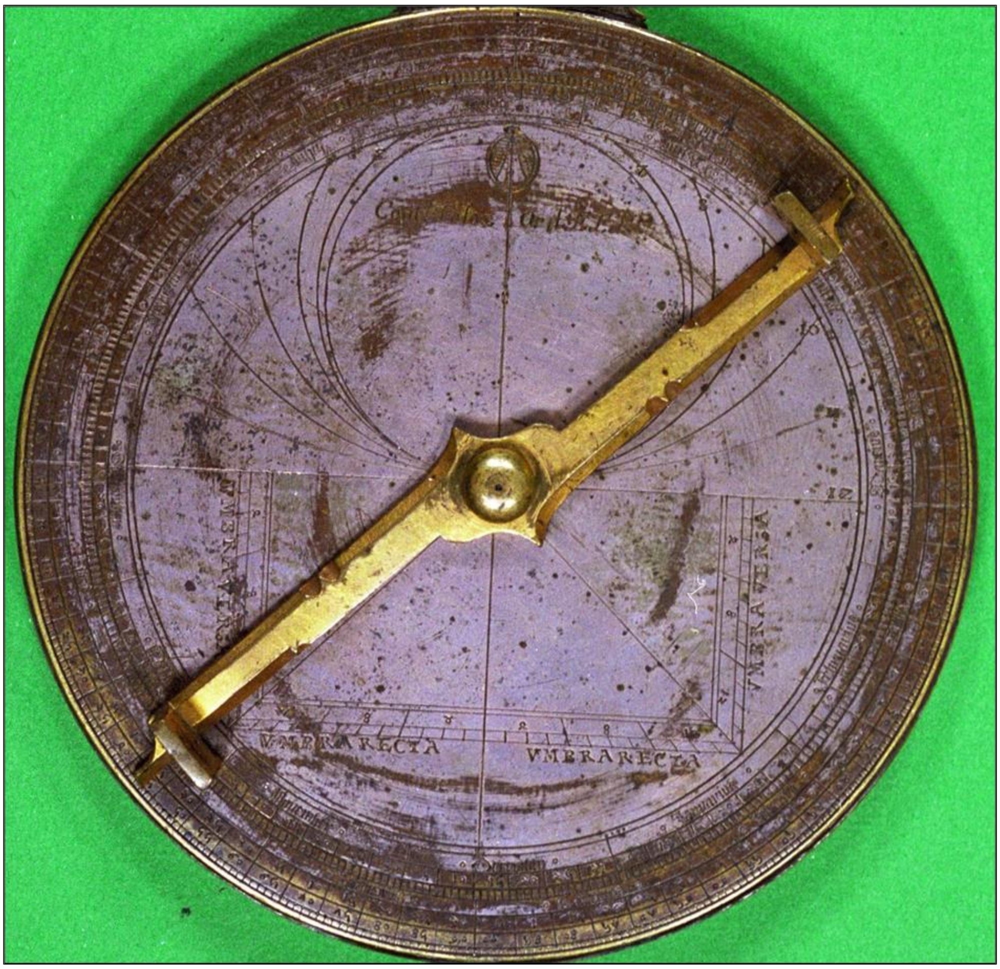

Figure 2: The alidade mounted on the back of the mater (photograph: Jacques Cadaugade).

Figure 3: Inscription on the back of the astrolabe's mater (photograph: Jacques Cadaugade).

stellations of the zodiac are generally engraved.

- A segment of a ring representing the Tropic of Capricorn.
- A horizontal bar showing the intersection of the plane of the celestial equator with that of the ecliptic. This bar cuts the rete into two equal parts, the right ascensions from 0 h to 12 h below, and those from 12 h to 24 h above.
- A certain number of pointers (34 for the present astrolabe) whose ends represent the locations of stars.

The rule is a bar for converting lengths into angular distances. It is generally graduated from +50° to –20°. The axis of rotation of the rule corresponds to the declination $\delta = 90°$. Two

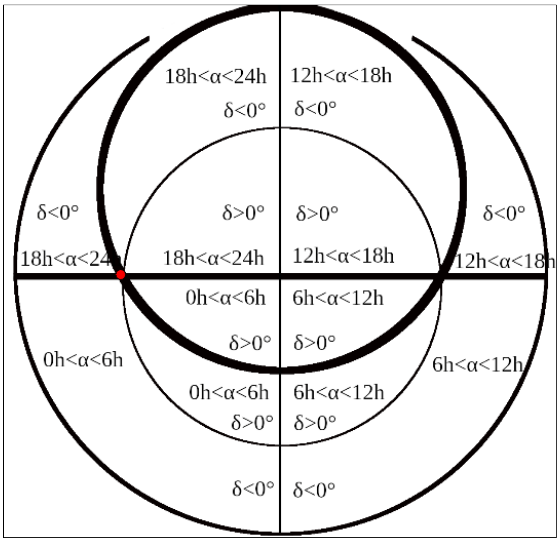

Figure 4: The different parts of the rete delimit the values of the right ascension (α) and declination (δ) (diagram: Emmanuel Davoust).

inscriptions are engraved on the rule: "LATITUDO SEPTENTR" and "LAT MERIDIO", and the declination 0° falls between these two inscriptions.

Figure 4 illustrates the values of the right ascension and declination in the different sectors of the rete. The right ascension gradually increases as the rule rotates counterclockwise. The declination, maximum (90°) at the center of the rete, decreases as we move away from the center. It becomes zero on the circle of the celestial equator (which is not represented on the rete of the present astrolabe), and negative outside this circle.

The left intersection between the circle of the celestial equator and that of the ecliptic is the vernal point (the small red point in Figure 4), which is the origin of the equatorial coordinates ($\alpha = 0$ h, $\delta = 0°$). The other intersection corresponds to $\alpha = 12$ h, $\delta = 0°$.

3 ORIGIN OF THE ASTROLABE

Currently, there are two astrolabes in the Musée des Arts Précieux Paul-Dupuy in Toulouse, France. The Arab astrolabe (inventory number 18088), constructed at the beginning of the thirteenth century by Abu Bekr ibn Yusuf, would have belonged to the Ariège astronomer Jacques Vidal (1747–1819), then to Abbot Vidalot-Tornier. The Latin astrolabe studied here comes from a convent of the Dominican preacher friars (probably the convent of Toulouse), as indicated by the inscription on the instrument (see Figure 3). It came into the possession of the Toulouse Observatory in Jolimont (inventory number 178) when its Director, Benjamin Baillaud, bought it "… from Mr. Argance, gilder rue des Chapeliers …" on 19 April 1899,[1] probably to illustrate his lectures at the university. It was deposited in the Museum by the Observatoire Midi-Pyrénées in July 2005.

4 DATING THE ASTROLABE

There is no date of manufacture on the astrolabe, nor are there star names on the rete's 34 pointers. To date the astrolabe, we determined the equatorial coordinates of the ends of the 34 pointers and produced a list of reference stars, then searched for the reference stars closest to each pointer for different dates.

To determine the equatorial coordinates of the tips of the pointers on the rete, we scanned a photographic print of the rete and the rule. The photograph was taken by a professional photographer using an analog camera and a professional reproduction stand. We then measured on the resulting image the positions of the ends of the different pointers and those of the center of the rete in a rectangular coordinate system, as well as the length of the rule in this same system of units (the pixel). The scale was 26.6 pixels/mm.

The right ascension, α, is given by the angle between the rule and the horizontal bar. This angle was determined in two ways: directly with a protractor on the paper print, and by calculation from the Cartesian coordinates on the image. The two methods gave results in good agreement (≤0.2° difference) and the second measurement, considered the more precise, was adopted as right ascension.

The declination, δ, is obtained by the equation:

$$\delta = \pi/4 - 2\text{atan}(r/l) \quad (1)$$

where r is the distance (in pixels) from the star to the center of the rete and l is the distance (in pixels) between the center of the rule and the graduation 0 on the rule, knowing that l corresponds to an angular distance of 90° in declination. The correspondence between δ and l is not linear, as shown by the above equation and by the tick marks on the rule which are increasingly tight closer to the axis of rotation.

As the rete does not include star names, we produced a list of bright stars inventoried on astrolabes from Tables 3.16, 3.17 and 12.4 of D'Hollander (1999), Table 4 in Torode (1992), and from the list of star names on Eastern astrolabes from the Adler Planetarium (Pingree, 2009) and two lists of astrolabe star names from the National Museum of American History (Tables IIA and IID in Gibbs and Saliba, 1984). Unfortunately, we were unable to access the work of Webster (1999) on the Latin astrolabes in the Adler Planetarium. The list of 113 reference stars is given in Table 1. The first four columns (Bayer designation, equatorial coordinates in sexagesimal format for the equinox 2000, proper motions in milliarcseconds per year, B magnitude) were taken from the SIMBAD database in 2012, when the research was done. Column 5 lists the frequency of occurrence of the star name in lists of the Adler Planetarium (A) and of the National Museum of American History (Sa and Si) and column 6 lists the occurrence in Table 4 of Torode (1992) when available. Note that Alpha Andromedae is the same star as Delta Pegasi and Beta Tauri is the same as Gamma Aurigae.

Table 1: Reference List of Stars.

Bayer Designation	Coordinates (J2000)		Proper Motions		Mag B	A,Sa,Sl	To
Alpha Andromedae	00 08 23.260	+29 05 25.55	137.46	–163.44	2.012	0, 3,0	
Beta Andromedae	01 09 43.924	+35 37 14.01	175.90	–112.20	3.64	6, 2,3	
Gamma Andromedae	02 03 53.953	+42 19 47.01	43.08	–50.85	3.550	3, 2,0	
Alpha Aquarii	22 05 47.036	–00 19 11.46	18.25	–9.39	3.905	0, 0,3	
Delta Aquarii	22 54 39.014	–15 49 14.98	–42.60	–27.89	3.344	16,20,2	
Alpha Aquilae	19 50 46.999	+08 52 05.96	536.23	385.29	0.99	29,34,5	131
Zeta Aquilae	19 05 24.608	+13 51 48.52	–7.25	–95.56	3.016	4, 3,0	
Theta Aquilae	20 11 18.266	–00 49 17.31	35.26	5.71	3.197	0, 0,0	
Xi Aquilae	19 54 14.882	+08 27 41.23	101.91	–81.20	5.769	0, 0,0	
Beta Arietis	01 54 38.411	+20 48 28.91	98.74	–110.41	2.77	1, 0,0	
Gamma Arietis	01 53 31.815	+19 17 37.88	79.20	–97.63	3.84	1, 0,0	
Delta Arietis	03 11 37.765	+19 43 36.04	153.33	–8.28	5.376	0, 1,0	
Alpha Aurigae	05 16 41.359	+45 59 52.77	75.25	–426.89	0.88	25,21,6	114
Beta Aurigae	05 59 31.723	+44 56 50.76	–56.44	–0.95	1.969	0, 1,0	
Alpha Bootis	14 15 39.672	+19 10 56.67	–1093.39	–2000.06	1.19	12,34,8	132
Beta Bootis	15 01 56.762	+40 23 26.04	–40.15	–28.86	4.431	0, 1,0	
Gamma Bootis	14 32 04.672	+38 18 29.70	–115.71	151.16	3.23	0, 0,2	
Epsilon Bootis	14 44 59.217	+27 04 27.21	–50.95	21.07	3.36	0, 0,1	
Eta Bootis	13 54 41.079	+18 23 51.79	–60.95	–356.29	3.250	0, 0,0	
Theta Bootis	14 25 11.797	+51 51 02.68	–235.40	–399.07	4.55	17, 0,0	
Alpha Cancri	08 58 29.223	+11 51 27.72	43.23	–29.63	4.401	1, 2,0	
Beta Cancri	08 16 30.921	+09 11 07.96	–46.82	–49.24	5.000	0, 1,0	
Epsilon Cancri	08 40 27.011	+19 32 41.31	–35.60	–12.98	6.460	0, 1,0	
Alpha Canis Majoris	06 45 08.917	–16 42 58.02	–546.01	–1223.07	–1.46	24,34,9	137
Zeta Canis Majoris	06 20 18.792	–30 03 48.12	7.32	4.03	2.83	1, 0,0	
Alpha Canis Minoris	07 39 18.119	+05 13 29.96	–714.59	–1036.80	0.74	27,32,7	128
Beta Canis Minoris	07 27 09.042	+08 17 21.54	–51.76	–38.29	2.814	0, 2,0	
Beta Capricorni	20 21 00.673	–14 46 52.98	44.92	7.38	3.87	1, 0,0	
Gamma Capricorni	21 40 05.456	–16 39 44.31	187.56	–22.45	4.00	1, 0,0	
Delta Capricorni	21 47 02.444	–16 07 38.23	261.70	–296.70	3.16	15,10,2	
Alpha Carinae	06 23 57.110	–52 41 44.38	19.93	23.24	–0.57	0, 0,0	
Alpha Cassiopeiae	00 40 30.441	+56 32 14.39	50.88	–32.13	3.434	0, 0,1	
Beta Cassiopeiae	00 09 10.685	+59 08 59.21	523.50	–179.77	2.61	24,21,0	
Alpha Ceti	03 02 16.773	+04 05 23.06	–10.41	–76.85	4.15	2,5,2	
Beta Ceti	00 43 35.371	–17 59 11.78	232.55	31.99	3.06	11,21,6	
Gamma Ceti	02 43 18.039	+03 14 08.94	–146.10	–146.12	3.56	13,23,0	
Zeta Ceti	01 51 27.635	–10 20 06.13	40.80	–37.25	4.873	5, 3,8	98
Iota Ceti	00 19 25.674	–08 49 26.11	–15.15	–37.11	4.782	21, 7,0	
Pi Ceti	02 44 07.349	–13 51 31.31	–8.62	–9.07	4.123	15, 0,0	
Tau Ceti	01 44 04.083	–15 56 14.93	–1721.05	854.16	4.22	1, 0,0	
Alpha Coronae Borealis	15 34 41.268	+26 42 52.89	120.27	–89.58	2.244	28,33,3	107
Alpha Corvi	12 08 24.817	–24 43 43.95	99.52	–39.19	4.34	0, 0,1	
Gamma Corvi	12 15 48.371	–17 32 30.95	–158.61	21.86	2.48	23,21,3	
Alpha Crateris	10 59 46.465	–18 17 55.62	–462.26	129.49	5.17	17,17,2	
Alpha Cygni	20 41 25.915	+45 16 49.22	2.01	1.85	1.34	24,28,5	96
Beta Cygni	19 30 43.281	+27 57 34.85	–7.17	–6.15	4.171	6, 8,0	

Delta Cygni	19 44 58.479	+45 07 50.92	44.07	48.66	2.881	0, 0,0	
Epsilon Cygni	20 46 12.682	+33 58 12.92	355.66	330.60	3.520	0, 0,0	
Epsilon Delphini	20 33 12.772	+11 18 11.74	11.96	–28.97	3.920	13, 6,3	
Alpha Draconis	14 04 23.350	+64 22 33.06	–56.34	17.21	3.640	4, 0,0	
Gamma Draconis	17 56 36.370	+51 29 20.02	–8.48	–22.79	3.760	0, 1,2	
Gamma Eridani	03 58 01.767	–13 30 30.67	61.57	–113.11	4.595	0,11,0	
Theta Eridani	02 58 15.675	–40 18 16.85	–52.89	21.98	3.03	17, ,0	
Tau Eridani	02 45 06.187	–18 34 21.21	334.20	37.19	4.95	0, 1,0	
Alpha Geminorum	07 34 35.873	+31 53 17.82	–191.45	–145.19	1.63	0, 2,1	
Alpha Herculis	17 14 38.858	+14 23 25.23	–7.32	36.07	4.51	6, 2,2	
Sigma Herculis	16 34 06.183	+42 26 13.35	–7.54	59.42	4.187	0, 0,0	
Tau Herculis	16 19 44.437	+46 18 48.11	–13.33	38.48	3.750	0, 0,0	
Alpha Hydrae	09 27 35.243	–08 39 30.96	–15.23	34.37	3.486	27,29,6	107
Sigma Hydrae	08 38 45.437	+03 20 29.17	–19.48	–15.92	5.678	3, 0,0	
Alpha Leonis	10 08 22.311	+11 58 01.95	–248.73	5.59	1.24	14,19,7	122
Beta Leonis	11 49 03.578	+14 34 19.41	–497.68	–114.67	2.23	1, 6,2	
Delta Leonis	11 14 06.501	+20 31 25.39	143.42	–129.88	2.68	2, 0,0	
Epsilon Leonis	09 45 51.073	+23 46 27.32	–45.61	–9.21	3.762	2, 0,0	
Alpha Librae	14 50 52.713	–16 02 30.40	–105.68	–68.40	2.912	1, 0,1	
Beta Librae	15 17 00.414	–09 22 58.49	–98.10	–19.65	2.535	2, 0,0	
Alpha Lyrae	18 36 56.336	+38 47 01.28	200.94	286.23	0.03	29,33,8	132
Alpha Ophiuchi	17 34 56.069	+12 33 36.13	108.07	–221.57	2.23	25,31,5	95
Delta Ophiuchi	16 14 20.739	–03 41 39.56	–47.54	–142.73	4.32	3, 0,2	
Zeta Ophiuchi	16 37 09.539	–10 34 01.53	15.26	24.79	2.595	3, 2,0	
Nu Ophiuchi	17 59 01.592	–09 46 25.08	–9.48	–116.69	4.31	0, 0,0	
Alpha Orionis	05 55 10.305	+07 24 25.43	27.54	11.30	2.27	22,27,3	95
Beta Orionis	05 14 32.272	–08 12 05.90	1.31	0.50	0.09	26,30,6	125
Gamma Orionis	05 25 07.863	+06 20 58.93	–8.11	–12.88	1.42	8, 4,0	
Kappa Orionis	05 47 45.389	–09 40 10.58	1.46	–1.28	1.937	9, 0,0	
Chi Orionis	05 54 22.983	+20 16 34.22	–162.54	–99.51	5.00	0, 4,2	
Alpha Pegasi	23 04 45.653	+15 12 18.96	60.40	–41.30	2.45	2, 0,6	
Beta Pegasi	23 03 46.457	+28 04 58.03	187.65	136.93	4.09	26,22,3	104
Gamma Pegasi	00 13 14.151	+15 11 00.94	1.98	–9.28	2.60	1, 2,0	
Epsilon Pegasi	21 44 11.156	+09 52 30.03	26.92	0.44	3.962	18,21,1	
Kappa Pegasi	21 44 38.735	+25 38 42.14	48.13	14.29	4.550	0, 0,0	
Tau Pegasi	23 20 38.242	+23 44 25.21	29.45	–9.53	4.756	0, 1,0	
Alpha Persei	03 24 19.370	+49 51 40.25	23.75	–26.23	2.286	0, 2,3	
Beta Persei	03 08 10.132	+40 57 20.33	2.99	–1.66	2.07	15,21,3	79
Omicron Persei	03 44 19.132	+32 17 17.69	8.18	–10.43	3.871	1, 0,0	
Alpha Piscis Austrini	22 57 39.046	–29 37 20.05	328.95	–164.67	1.25	0, 1,0	
Zeta Puppis	08 03 35.048	–40 00 11.33	–29.71	16.68	1.97	1, 0,0	
Rho Puppis	08 07 32.649	–24 18 15.57	–83.35	46.23	3.24	4, 2,1	
Rho Sagitarii	19 21 40.359	–17 50 49.92	–25.87	21.46	4.149	2, 0,0	
Alpha Scorpii	16 29 24.460	–26 25 55.21	–12.11	–23.30	2.96	18,23,3	85
Beta Scorpii	16 05 26.232	–19 48 19.63	–5.20	–24.04	2.55	0, 0,0	
Delta Scorpii	16 00 20.005	–22 37 18.14	–10.21	–35.41	2.205	0, 0,0	
Lambda Scorpii	17 33 36.520	–37 06 13.76	–8.53	–30.80	1.48	0, 0,0	
Alpha Serpentis	15 44 16.074	+06 25 32.26	133.84	44.81	3.800	23,24,0	
Rho Serpentis	15 51 15.910	+20 58 40.52	–53.32	18.87	6.301	1, 0,0	
Alpha Tauri	04 35 55.239	+16 30 33.49	63.45	–188.94	2.468	24,33,8	133
Beta Tauri	05 26 17.513	+28 36 26.83	22.76	–173.58	1.62	0, 2,0	
Eta Tauri	03 47 29.077	+24 06 18.49	19.34	–43.67	2.806	0, 0,1	
Alpha Trianguli	01 53 04.907	+29 34 43.78	10.82	–234.24	3.90	0, 3,0	
Alpha Ursae Majoris	11 03 43.672	+61 45 03.72	–134.11	–34.70	2.86	17,12,3	
Beta Ursae Majoris	11 01 50.477	+56 22 56.73	81.43	33.49	2.376	0, 0,1	
Gamma Ursae Majoris	11 53 49.847	+53 41 41.14	107.68	11.01	2.450	0, 0,0	
Delta Ursae Majoris	12 15 25.561	+57 01 57.42	104.11	7.30	3.410	0, 0,0	
Epsilon Ursae Majoris	12 54 01.750	+55 57 35.36	111.91	–8.24	1.801	1, 0,1	
Zeta Ursae Majoris	13 23 55.540	+54 55 31.27	119.01	–25.97	2.29	6, 2,0	
Eta Ursae Majoris	13 47 32.438	+49 18 47.76	–121.17	–14.91	1.755	6, 3,3	74
Theta Ursae Maioris	09 32 51.434	+51 40 38.28	–947.46	–535.60	3.63	0, 0,0	
Iota Ursae Majoris	08 59 12.454	+48 02 30.57	–441.29	–215.32	3.33	0, 0,1	
Mu Ursae Majoris	10 22 19.740	+41 29 58.27	–81.47	35.34	4.672	5, 2,0	
Xi Ursae Majoris	11 18 10.9	+31 31 44	–430.00	–588.00	4.38	0, 0,0	
Alpha Ursae Minoris	02 31 49.095	+89 15 50.79	44.48	–11.85	2.591	0, 2,0	
Alpha Virginis	13 25 11.579	–11 09 40.75	–42.35	–30.67	0.91	27,33,7	129
Epsilon Virginis	13 02 10.598	+10 57 32.94	–273.80	19.96	3.77	1, 2,0	

Although they constitute the sphere of 'fixed stars', stars do not have time-independent coordinates. These coordinates change regularly because of the precession of the equinoxes, a consequence of the slow change in direction of the earth's axis of rotation. Additionally, stars have small relative displacements with respect to each other, called proper motions. It is precisely these changes in coordinates over time that make it possible to date a catalog of stars.

We calculated the coordinates of the stars listed in Table 1 for all equinoxes between 1400 and 1700 with a step of 50 years, using the precession equations given in the Astronomical Almanac for 2005, page B18. We took into account the proper motions of the stars in these calculations, although the effect of these displacements is small compared to the uncertainties of the coordinates on the astrolabe. Finally, we compared these coordinates with those of the ends of the 34 pointers for each equinox and found the most probable equinox, 1550, by minimizing the difference between the coordinates of the pointer ends and those of the associated stars. We tried to improve the agreement between the position of the reference stars and that of the pointer ends by slightly modifying the coordinates of the center of the rete, or the length of the rule, or by using the 1570 and 1530 equinoxes. The 1550 equinox remains the one that gives the best agreement. Interestingly, among the astrolabes inventoried by Price (1955), the largest number of Latin ones are dated from 1550.

As two pointer ends (11 and 16) have no matches in our reference list, we searched for other possible candidates in the SIMBAD database. To do this, we limited ourselves to stars brighter than magnitude 5 and with proper motions. We calculated the coordinates of these stars for the 1550 equinox. We were thus able to find two stars not used by astrolabists, 16 Lyncis which is in poor agreement with pointer 11 and Phi Leonis, which is in poor agreement with pointer 16. These two identifications are of low confidence.

The stars associated with the 34 pointers are listed in Table 2, which gives the number of the pointer, the equatorial coordinates (RAp and Decp, in sexagesimal format) of the pointer as derived by our measurements, as well as the coordinates (RA* and Dec*) for the 1550 equinox, separation in degrees, name and V magnitude of the star associated with this pointer in

Table 2: Catalog of the Astrolabe's Stars.

Np	RAp	Decp	RA*	Dec*	Sep	Name	magV	A,Sa,Sl	To	Pointer
1	00h14	54°57	00h15	+54°03	0.9	Alpha Cassiopeiae	v2.2	0, 0, 1		
2	00h16	–19°33	00h20	–20°28	1.3	Beta Ceti	2.0	11, 21, 6		
3	00h40	34°23	00h45	+33°12	1.6	Beta Andromedae	2.0	6, 2, 3		
4	02h47	48°32	02h53	+48°09	1.1	Alpha Persei	1.8	0, 2, 3		
5	03h39	–14°19	03h37	–14°51	0.7	Gamma Eridani	3.0	0, 11, 0		
6	04h11	15°27	04h10	+15°30	0.2	Alpha Tauri	0.8	24, 33, 8	133	
7	04h44	45°19	04h43	+45°24	0.2	Alpha Aurigae	0.1	25, 21, 6	114	
8	04h52	–09°21	04h53	–08°48	0.6	Beta Orionis	0.2	26, 30, 6	125	
9	05h31	06°21	05h30	+07°13	0.9	Alpha Orionis	0.8	22, 27, 3	95	
10	06h23	–15°30	06h25	–16°10	0.8	Alpha Canis Majoris	–1.4	24, 34, 9	137	
11	06h40	45°16	06h24	+45°32	2.8	16 Lyncis	4.9			
12	07h13	06°35	07h16	+06°17	0.8	Alpha Canis Minoris	0.4	27, 32, 7	128	
13	07h26	16°35	07h52	+10°28	8.8	Beta Cancri	3.5	0, 1, 0		straight
14	08h18	50°19	08h28	+49°42	1.7	Iota Ursa Majoris	3.2	0, 0, 1		
15	08h21	–08°55	09h05	–06°46	11.1	Alpha Hydrae	2.0	27, 29, 6	107	
16	10h48	–04°31	10h54	–01°12	3.6	Phi Leonis	4.5			
17	11h14	31°47	10h54	+34°02	4.8	Xi Ursa Majoris	2.3	0, 0, 0		
18	11h23	56°29	11h29	+56°12	0.9	Gamma Ursa Majoris	2.4	0, 0, 0		
19	12h01	–15°57	11h52	–15°02	2.4	Gamma Corvi	2.6	23, 21, 3		
20	13h02	–13°50	13h02	–08°46	5.1	Alpha Virginis	v1.0	27, 33, 7	129	straight
21	13h02	19°57	13h33	+20°41	7.3	Eta Bootis	2.7	0, 0, 0		
22	13h33	11°03	12h39	+13°24	13.4	Epsilon Virginis	2.8	1, 2, 0		
23	15h10	29°38	15h16	+28°17	1.9	Alpha Coronae Borealis	v2.3	28, 33, 3	107	
24	15h33	–19°56	15h34	–21°14	1.3	Delta Scorpii	2.3	0, 0, 0		
24			15h33	–21°14	1.3	Beta Scorpii	2.6	0, 0, 0		
25	16h18	43°40	16h19	+43°25	0.3	Sigma Herculis	4.2	0, 0, 0		
26	16h44	15°14	16h54	+14°59	2.4	Alpha Herculis	3.1	6, 2, 2		
27	17h56	14°30	17h14	+12°57	10.3	Alpha Ophiuchi	2.1	25, 31, 5	95	straight
28	19h 6	44°43	19h31	+44°05	4.5	Delta Cygni	2.9	0, 0, 0		
29	19h41	–01°13	19h48	–02°04	1.9	Theta Aquilae	3.2	0, 0, 0		
30	20h20	43°47	20h26	+43°43	1.1	Alpha Cygni	1.2	24, 28, 5	96	
31	20h24	–20°06	20h03	–19°12	5.0	Rho Capricorni	4.8	0, 0, 0		straight

31			20h19	–26°49	6.8	Psi Capricorni	4.1	0, 0, 0		
31			19h56	–16°06	7.8	Beta Capricorni	3.1	0, 0, 0		
32	22h13	23°03	22h22	+27°54	5.3	Eta Pegasi	3.8	0, 0, 0		
33			22h42	+25°40	7.1	Beta Pegasi	v2.4	26, 22, 3	104	
33	22h17	–17°20	22h31	–18°11	3.4	Delta Aquarii	3.3	16, 20, 2		broken
34	22h37	10°10	22h42	+12°48	2.9	Alpha Pegasi	2.5	2, 0, 6		

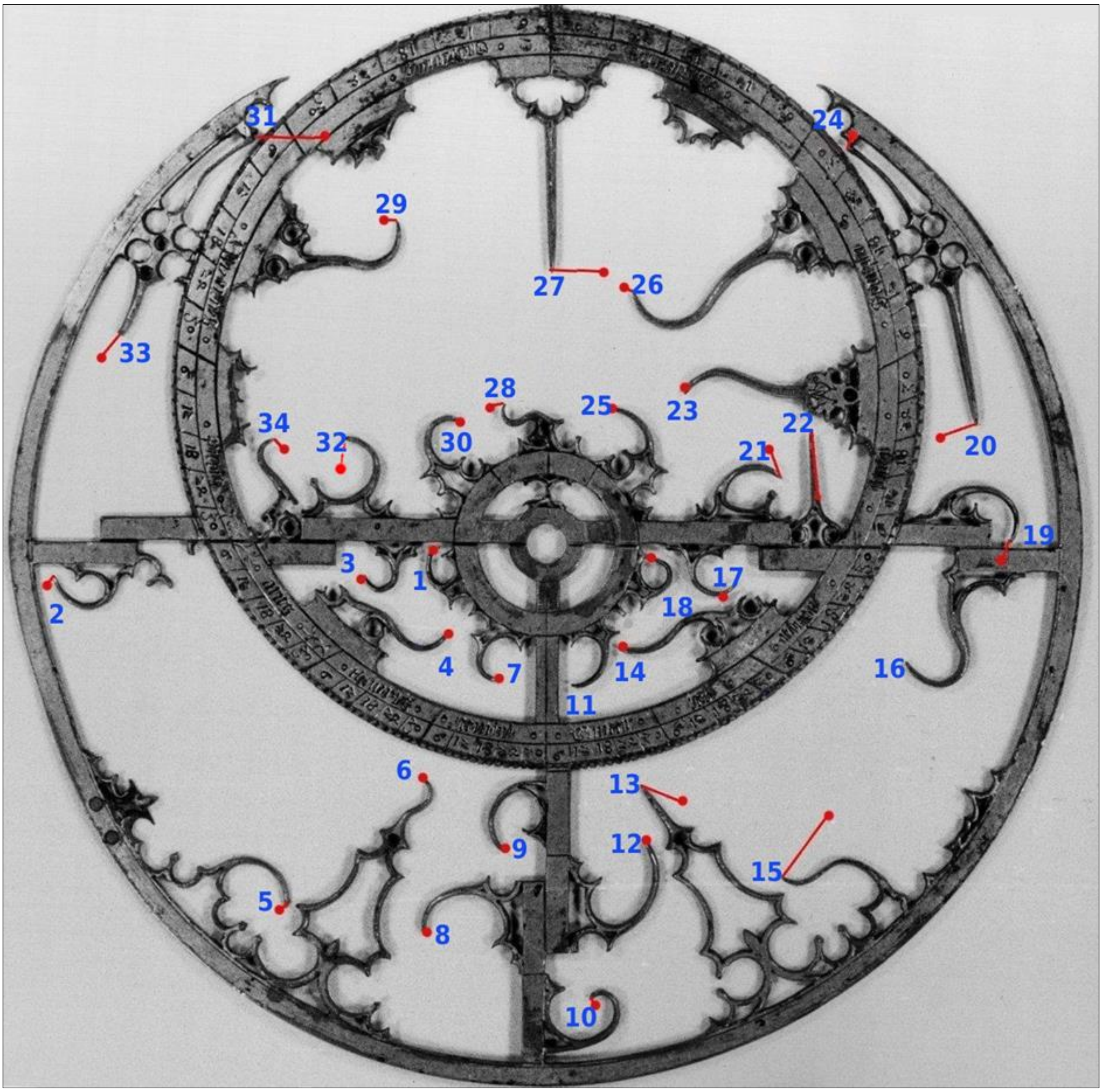

Figure 5: The rete, pointers (blue numbers) and reference stars (red dots) (photograph modification: Emmanuel Davoust).

columns 1 to 8. A v in front of the magnitude indicates a variable star. Columns 9 and 10 give the number of astrolabes on which these stars were identified in the different lists. The last column mentions straight or broken pointers, where applicable. In a few cases we have indicated several stars as possible counterparts.

Figure 5 shows the qualitative agreement between the ends of the pointers (numbered in blue) and the associated stars (red dot), which in 24 of 34 cases is very satisfactory, the angular separation being less than four degrees. In four cases (13, 20, 22, 27), the pointer is straight and the agreement poor, suggesting that the astrolabe remained unfinished. In one case (33), the pointer is broken, and a bright star is in its extension. In summary, there are only two pointers (11, 16) without a star used by other astrolabes, and to which we could not associate a star from the reference list.

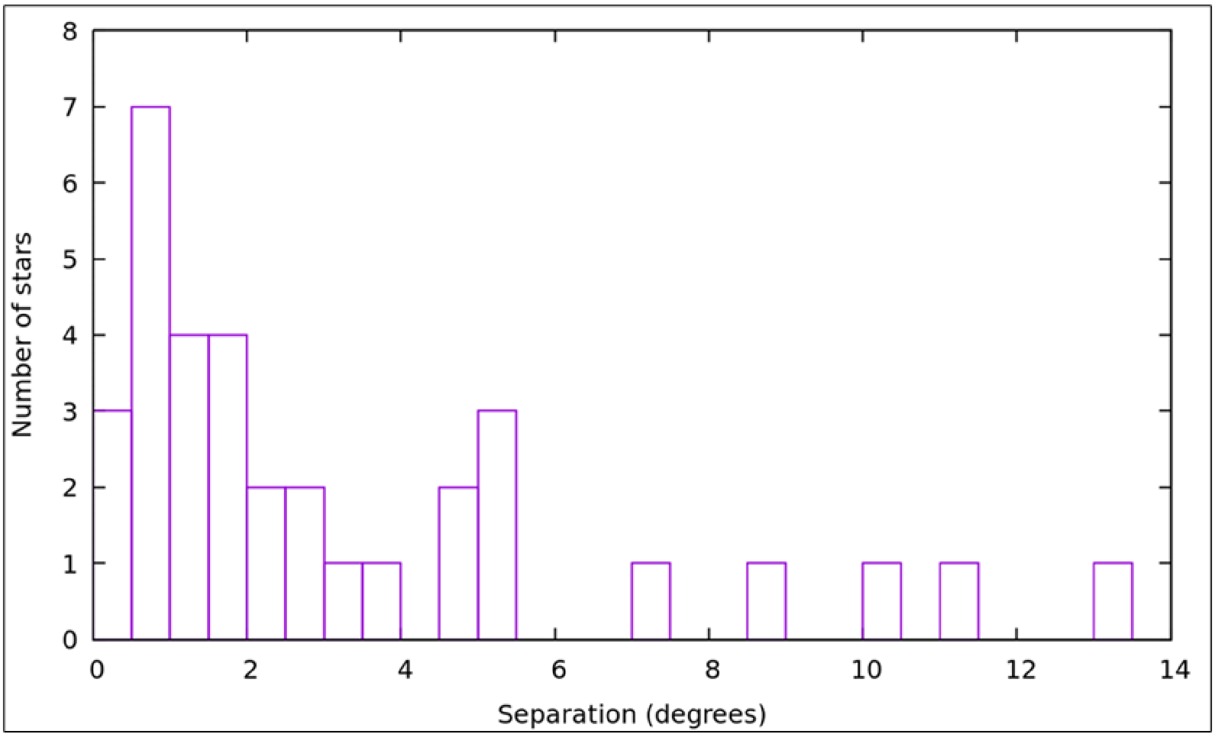

Figure 6: Histogram of the separations between stars and pointers (plot: Emmanuel Davoust).

We have determined that the 1550 equinox is the most probable one for the catalog of stars. But the accuracy of this value is difficult to estimate. Since the astrolabe results from a double stereographic projection, the scale is not uniform across the rete. For example, an error of 4 pixels (0.15 mm) in the measurements corresponds to an error of 0.6° at δ = 0°, of 1° at δ = 40° and of 2° at δ = 80°. The histogram of separations between star and pointer (Figure 6) shows a regular decrease to 4°, and then 10 outliers. We assume that errors or inaccuracies in the catalog of stars used in the construction of this astrolabe are at the origin of these outliers, and attribute the distribution of the 24 others to uncertainties in our measurements of the tips of the pointers and to minor defects in the construction of the astrolabe. The average separation of 1.5° corresponds to an uncertainty of about 90 years in the equinox. This estimate can be compared to the standard deviation of 86 years for the difference in the date calculated from the precession and obtained by other means by Torode (1992) for 11 Flemish astrolabes which he found were the most accurate ones that he studied.

Torode (1992) gives a list of the 20 most popular stars on the 137 astrolabes that he studied. They were all represented on at least 74 astrolabes. Among them, eight were not used for this astrolabe despite their high frequency. Did our method overlook them in the search for matching stars, or did the astrolabist ignore them? Figure 7 shows the location of the eight missing stars. The star Beta Per (Algol) would have given a poorer agreement with the pointer four than the brighter star Alpha Per (Mirfak). The stars Alpha Aql, Alpha Lyr and Alpha Boo, although very bright, are more than 10° from the nearest pointer. The other four stars could not have been part of the catalog without the addition of pointers to the rete.

5 PECULIARITIES OF THE ASTROLABE

This astrolabe is not signed. As we dated to 1550 the star catalog which was used to construct it, we could attribute its construction to a member of the Flemish school of astrolabists of that time, in particular to the itinerant astrolabist Adrien Descrolières (active in the second half of the sixteenth century), because Dominican preacher friars of Toulouse owned an unsigned astronomical quadrant by Descrolières, which is currently also in Musée des Arts Précieux Paul-Dupuy. But the rete of that quadrant looks nothing like the one on our astrolabe. A more-likely possibility, suggested by Raymond d'Hollander (private communication) is that the Dominican preacher friars (or whoever owned the astrolabe before them) asked an Arabic astrolabist to produce an instrument with Gothic inscriptions, because the European astrolabists did not acquire a real know-how until the early fifteenth century. David King himself (private communication) thinks that it is a copy of an Arabic astrolabe.

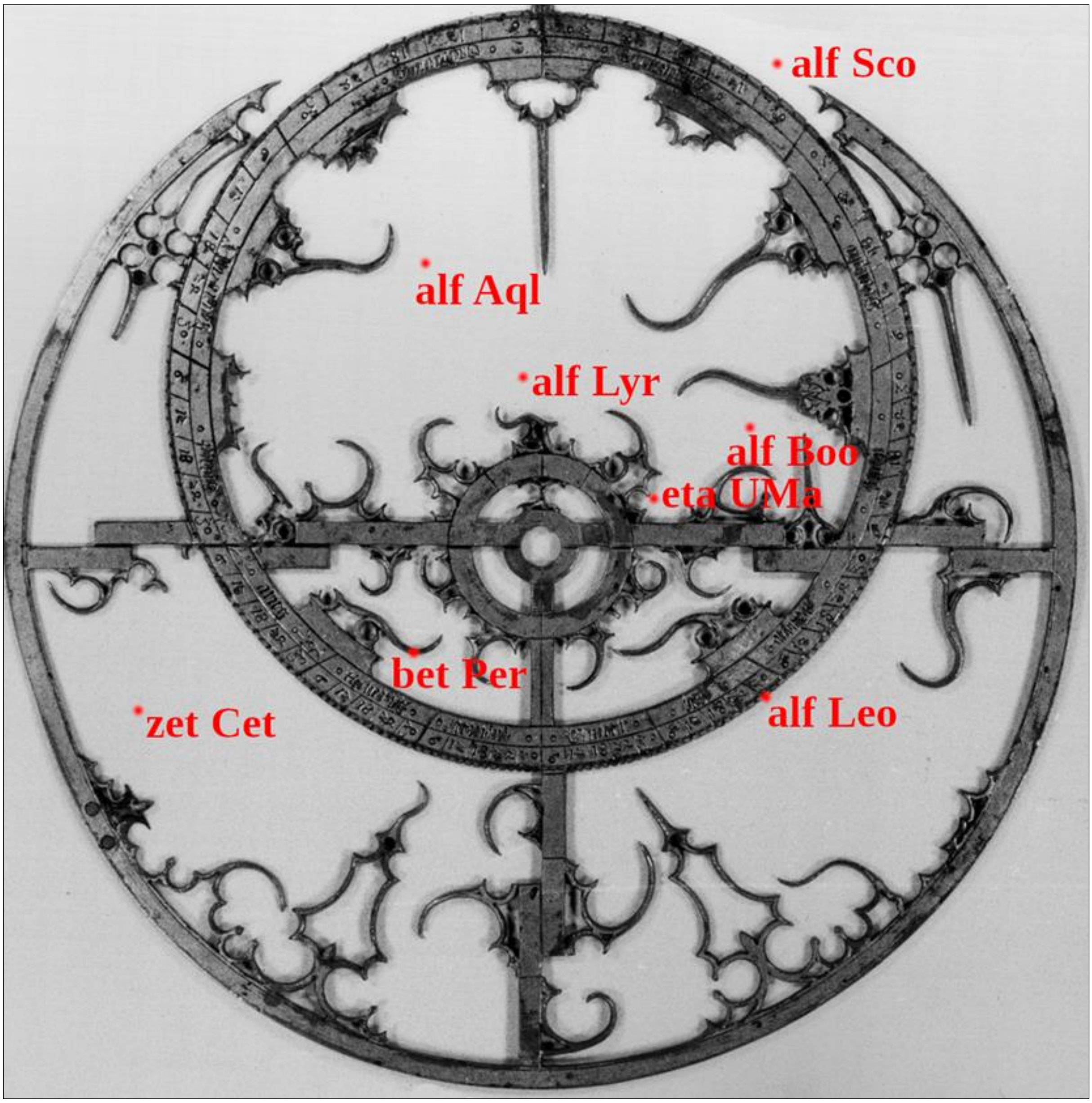

Figure 7: Positions of the eight stars in Torode's (1992) list absent from the astrolabe's star catalog (photograph modification: Emmanuel Davoust).

There are 34 star pointers on the astrolabe of the Dominical preacher friars. This is a relatively large number compared to the number on the various astrolabes described in the two major monographs, those of Pingree (2009) and Gibbs and Saliba (1984). In the Adler Planetarium collection, four out of 29 astrolabes have more than 33 stars, and for those in the National Museum of American History the figure is one of 35 Arabic astrolabes and zero of eight Latin astrolabes. The Spanish astrolabe studied by King (2003) has 21 stars. The histogram in Figure 8, based on three lists of astrolabe stars, shows that on average an astrolabe has 27 stars. The Gaussian fitted to the histogram has a standard deviation of 4.5. The difference in the number of stars in our astrolabe from the average is therefore significant.

6 NOTES

1. Invoice of Mr. Argance to Faculté des Sciences de Toulouse, April 19, 1899. Municipal Archives of Toulouse, inventory number 2R 48.

7 ACKNOWLEDGMENTS

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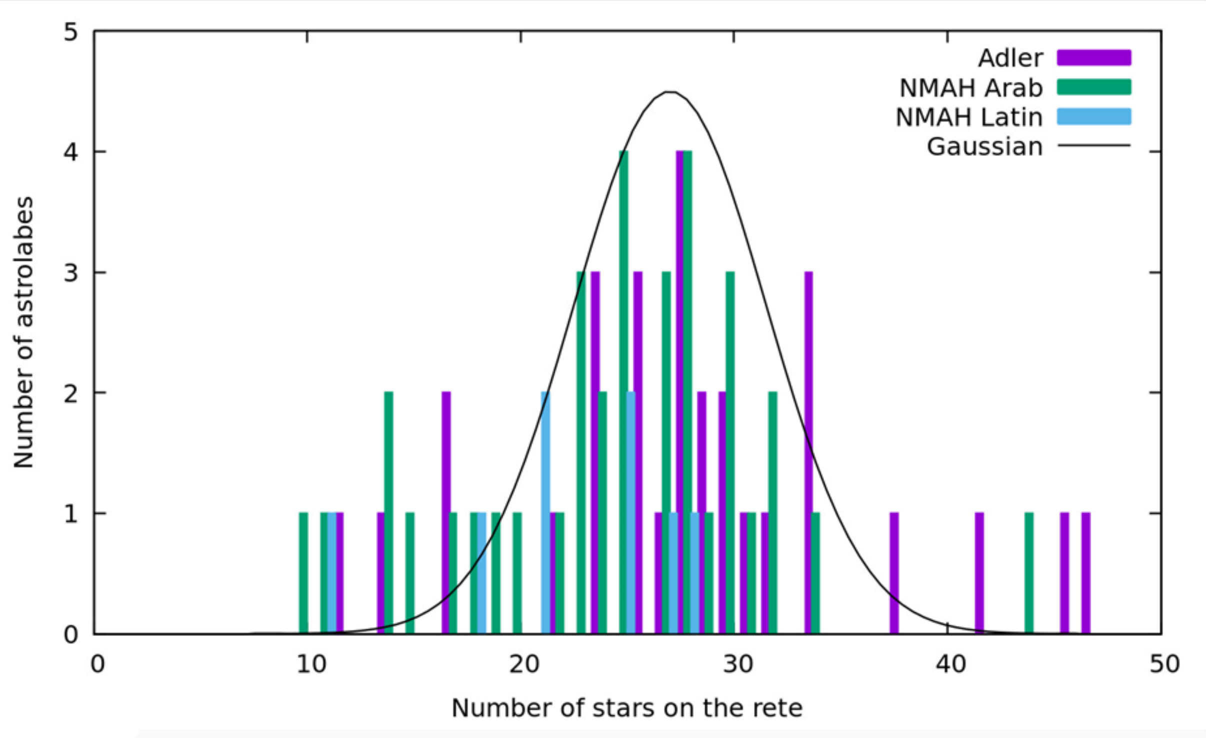

Figure 8: Histogram of the number of stars on astrolabes in three lists of astrolabe stars (plot: Emmanuel Davoust).

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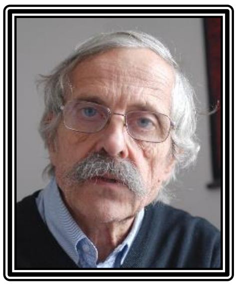
Dr. Emmanuel Davoust was born in Stockholm in 1946. He obtained a BSc in Physics from the French University in Beirut in 1970 and an MSc in Astronomy from the University of Toronto in 1972. After completing one year of military service, he joined Besançon Observatory, observing with the meridian circle and doing research on globular clusters. He obtained the degree *Doctorat de Troisième Cycle* on the dynamics of globular clusters under the supervision of Michel Hénon in 1980. He then spent a year at the University of Texas at Austin, working with Gérard de Vaucouleurs on spiral galaxies and with Roger Broucke on problems of celestial mechanics. He obtained the degree *Doctorat Etat* under the supervision of Gérard de Vaucouleurs in 1983. Three years later he joined the

Observatoire Midi-Pyrénées in Toulouse where he studied the morphology and dynamics of elliptical galaxies, starburst galaxies and globular clusters in external galaxies.



While his main research interest was in stellar systems, he also published papers on celestial mechanics (the general three-body problem) and in bibliometry (the publishing activity of astronomers, and the role of references in astronomy). His duties as astronomer included teaching at the Université Paul Sabatier, giving conferences in popular astronomy, and contributing to the maintenance of the SIMBAD database at Strasbourg Observatory.

He has been a member of the Heritage Commission of the Observatoire Midi-Pyrénées since its foundation in 1992, saving, inventorying and restoring old astronomical instruments and photographic plates.

He is the author of a book on the search for life in the Universe, which has been translated into five foreign languages, and a book on the history of Pic du Midi Observatory, which is also available in English.

Emannuel retired in 2012 and was an Astronomer Emeritus until 2018, active in the Heritage Commission.