# Archeometry and reverse engineering to understand how clockmakers build timekeepers in the 17th century: the Simon Le Noir Project and ArcheHor

Augustin GOMAND – CHRONOSPEDIA

ESPADON working session – 17 January 2025

Projet Simon Le Noir

CHRONOSPEDIA
TECHNICAE SCIENTIAE CUSTOS PER TEMPUS

LGPM
GÉNIE DES PROCÉDÉS ET MATÉRIAUX

LMPS

ZEISS

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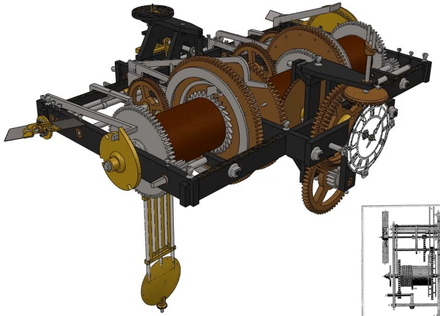
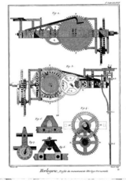
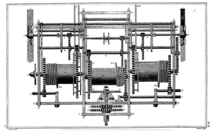
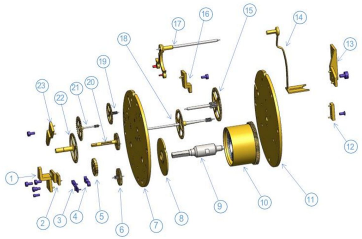
NÉEL institut

CENTRE DE RECHERCHE ET DE RESTAURATION DES MUSÉES DE FRANCE

# CHRONOSPEDIA

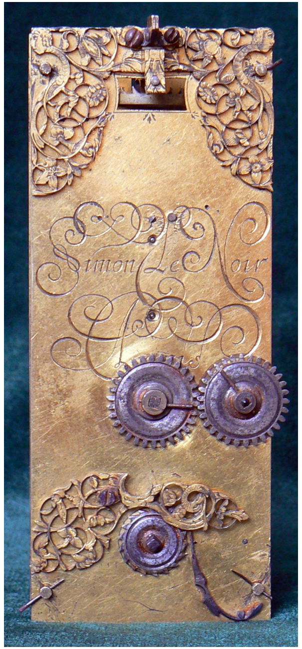
- CHRONOSPEDIA is a humanist project that aims at **preserving and passing on clockmaking know-how** using the latest innovations (3D, VR, AR, archiving, *etc.*)
- Coordinators: François SIMON-FUSTIER (l'Horloger de la Croix Rousse), Konstantin PROTASSOV (professor at UGA)
- CHRONOSPEDIA brings together **more than forty organisations**: museums (Musée du Temps de Besançon…), schools (Lycée Diderot, Grenoble INP…), research institutes (LS2N, INIST…), *etc.*
- CHRONOSPEDIA's activities are currently focused on creating 3D models of clock mechanisms (by direct modelling or photogrammetry) to help understand how they work and diagnose faults → educational approach
- Several other activities: database of ancient clock sounds (Maison des Sciences de l'Homme), Ph.D. on artificial intelligence for reverse engineering… + **support to the Simon Le Noir project**
- Website: https://chronospedia.com/s/chronospedia/page/home



# The Simon Le Noir Project

- Project initiated in October 2020 following the discovery of a mechanism signed Simon Le Noir (seen from the back on the figure at right)
- The mechanism has several special features that are not seen on the first known pendulum clocks, but most related to the Renaissance era (pre-1658)
- Anecdote reported in a manuscript by Claude Raillard (~1720): Simon Le Noir would have been the first to apply the pendulum in France according to his son, Jean-Baptiste
- Main objectives of the project:
  - Detailed analyses of the mechanism from a technical & stylistic point of view
  - Historical researches on Simon Le Noir and the first pendulum clocks
  - Formulation of hypotheses on the place of the studied mechanism in the history of clockmaking
- First articles published in specialized journals in 2022 [1], 2023 [2] & 2024 [3]
- Website: https://agomand.github.io/asln/en
- Other publications to follow in 2025



[1] [1] Gomand, A., 2022. *Simon Le Noir et l'application du pendule aux horloges : une histoire parallèle ?* Horlogerie Ancienne 91, pp. 16-44
[2] [2] Gomand, A., 2023. *Compléments dans l'affaire Simon Le Noir*. Horlogerie Ancienne 93, pp. 16-42
[3] [3] Gomand, A., 2024. *Experimenting with the pendulum: the work of Tito Livio Burattini (1617-1681)*. Antiquarian Horology 45 (1), pp. 63-87

# Context and objectives of the project

- Analysis of the Le Noir mechanism to authentify it & identify possible modifications / repairs
- Clocks are generally authentified through macroscopic analyses based on mechanism layout, techniques of construction and stylistic / technical features
- <u>Difficulty</u>: fakers are more and more skilled in making forgeries, especially since the 20th century (*e.g.* the drum watch signed "Petrus Hele" [4], similar difficulty encountered for scientific instruments [5])
- How to authentify an artefact without clear, objective, scientific authentication criteria? Classical problem in archaeology: techniques not documented, most of the know-how was transmitted orally and during the apprenticeship ("compagnonnage"), and therefore was kept only inside the guild of the clockmakers, while first horological treatises published in the 18th century are most of the time theoretical and do not go into the details = **almost no existing primary bibliographical source**

→ need to reconstruct / extrapolate the horological know-how directly by analyzing mechanisms

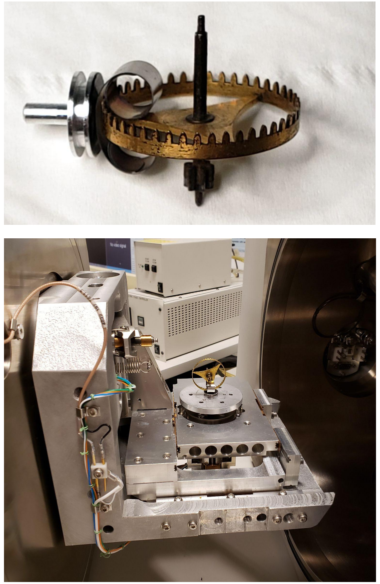
→ basis of **reverse engineering** coupled to **archeometry and experimental archaeology**

→ **the Le Noir mechanism will be used as a "witness" artefact to test new archaeological protocols applied to timekeepers**

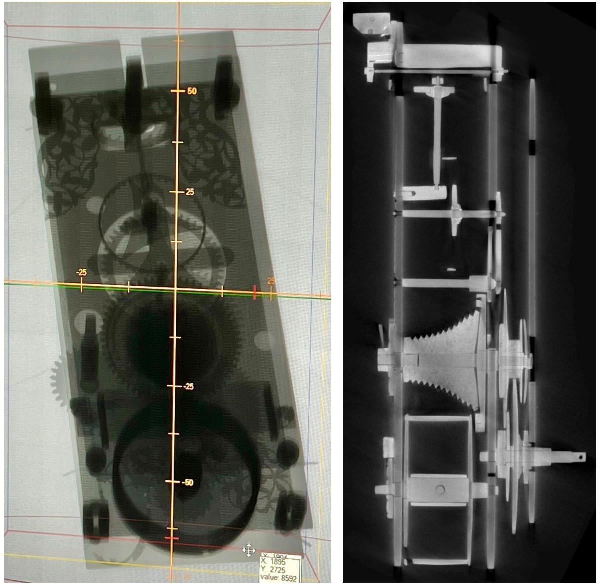
[4] [4] Ehrt, J., 2021. *Ein Mythos auf dem Prüfstand [...]*. Restaurierungsatelier Jürgen Ehrt.
[5] [5] De Clercq, P., 1999. *Scientific instruments – originals and imitations: the Mensing connection – proceedings of a symposium, held at the Museum Boerhaave, Leiden, 15-16 October 1999*

# Scientific analysis methods

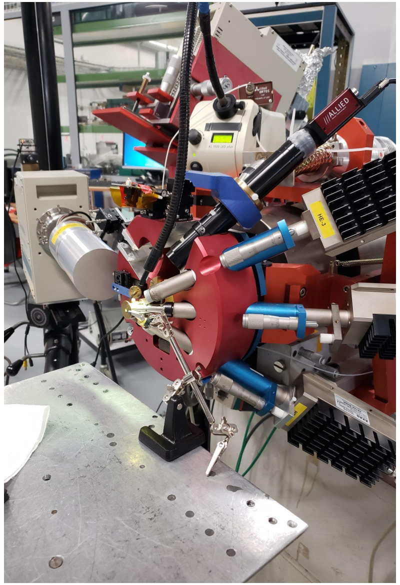
- Types of analyses carried out: optical / electron microscope examinations (**left**), tomographies (**centre**), X-ray fluorescence elemental composition analyses using SEM-EDX, XRF and PIXE (**right**).



*Scanning electron microscope (LGPM)*



*Tomography (Zeiss)*



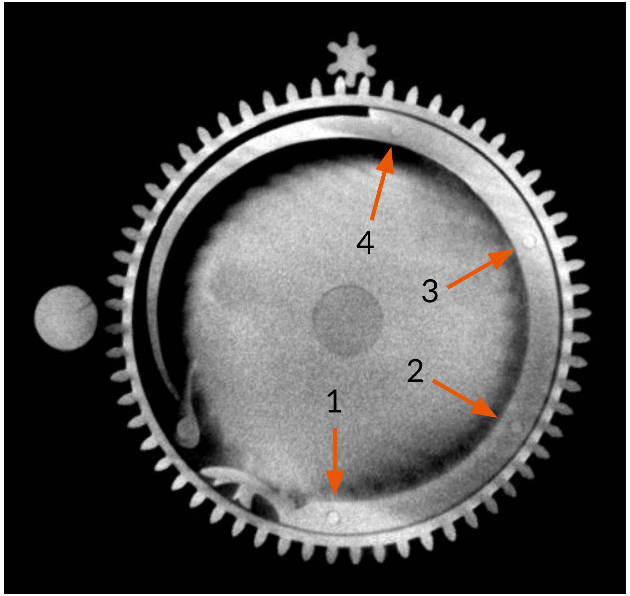
*PIXE (NEW AGLAE, C2RMF)*

# Authenticate through the techniques

- Key primary source: manuscript discovered in the papers of the scholar John Evelyn [6, 7] which describes in detail the manufacture of all the components of a mid-17th-century watch as well as a large number of tools, metallurgical techniques, *etc.* → **can be used for authentication**
- Some examples of techniques described in the manuscript and observed on the Le Noir mechanism:

*"... the spring is being cut round out of the whole brass, & well hammered then fitted, & fashioned with files only,* ***it is riveted also into the hollow of the great wheel, with 3 or 4 rivets****"*[8]

→ this spring is indeed riveted, the rivets are covered by gilding but visible on cut views (see figure at right, rivets visible at the end of the arrows)




[6] [6] British Library: Add. MS 78425 – Evelyn Papers. Vol. CCLVIII, fol. 8 recto - 14 recto

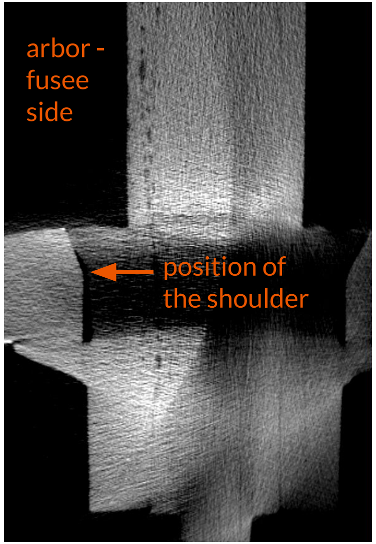
[7] [7] Thompson, D., 2023. *'Summe Dyrections towards the makinge of a smale watch, of brasse' – A guide to watchmaking techniques in the seventeenth century.* Antiquarian Horology 44 (2), pp. 179-206

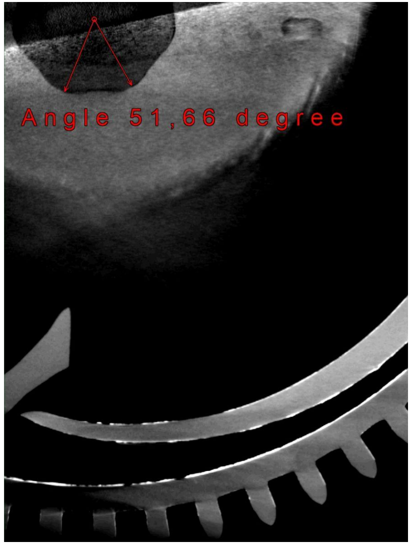
[8] [6] Evelyn papers, folio 11 verso

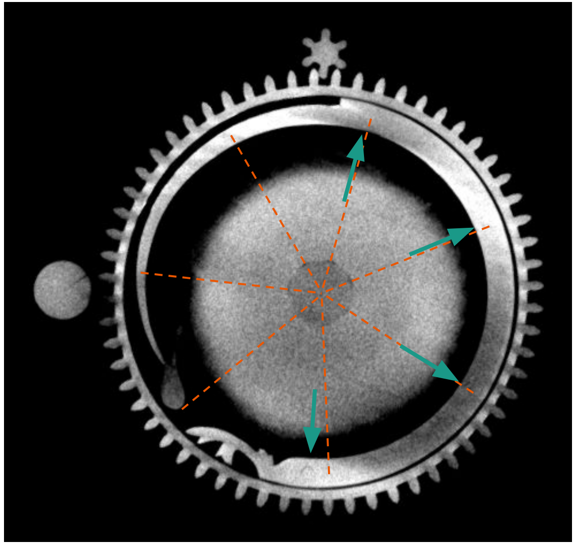
# Authenticate through the techniques

*"The arbor of the great wheel is in like sort* ***riveted thereunto with a shoulder left in the turning of the arbor without the soldering of any brass thereunto****"* [9]

→ the fusee arbor has an heptagonal shoulder which is located at mid-height in the wheel, the edges of the shoulder are pointing towards the 4 rivets of the spring that **may have been used as "markers"**



[9] [6] Evelyn papers, folio 10 recto

# Understand the techniques

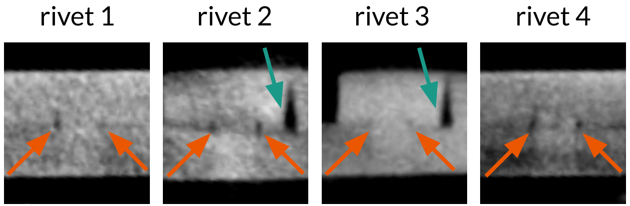
- On the cut views of the great wheel, chamfers can be noticed around each rivet at the junction between the wheel plate and the spring

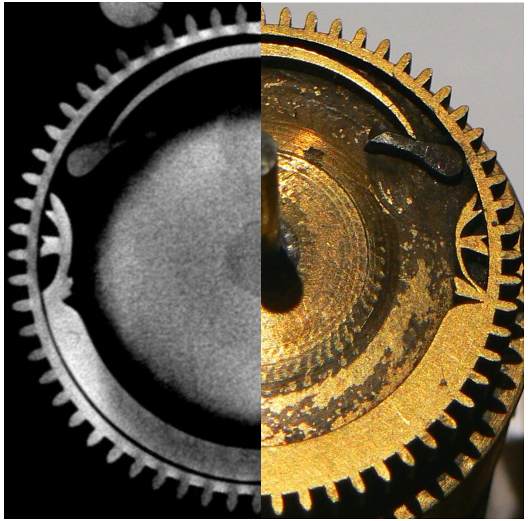
  → these chamfers were used to facilitate the installation of the spring by guiding its positioning

  → most probably, the rivets were first put in the wheel before the spring was fixed on them
- There is a gap between the spring and the edge of the "hollow" where it is housed, which is not visible from the outside

  → the side of the spring was bevelled to make it easier to fit into the hollow

  → the top of the spring was then hammered to cover the gap between the 2 parts (spring & wheels), so as to remove all traces of the assembly
- **We have therefore finally reconstructed the entire manufacturing sequence of this assembly**



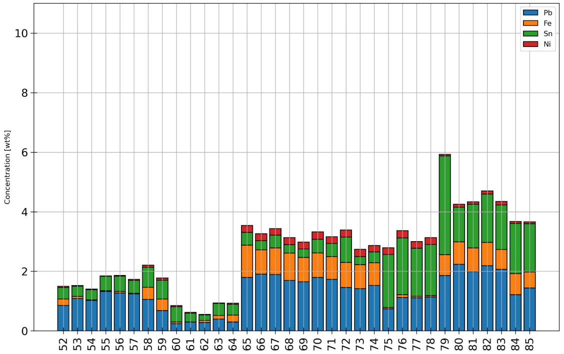



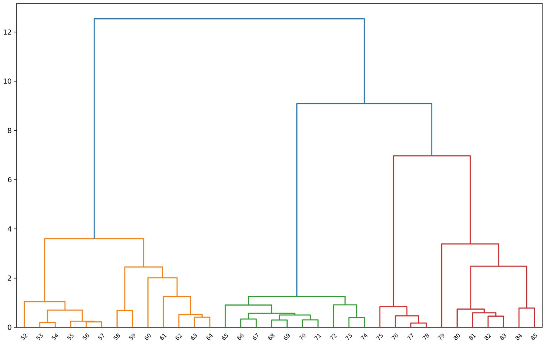
# Characterize the materials

- Fluorescence analyses can be used to characterise the chemical compositions of brass from which the various parts of the mechanism are made

  → it is possible to **classify the parts into different groups** determined according to elementary concentrations
- Principle of **automatic classification methods**: "to discover empirically useful and objectively defined classes in a given universe" [10]
- Application to archaeology in the 1970s thanks to developments in information technology [11]
- Brass: hierarchical agglomerative clustering (HAC) based on centred and standardised values of zinc, lead, tin, iron and nickel concentrations

  → drawing of **dendrogram** (see figures at right for a mechanism attributed to Claude Raillard, dated c.1660-62)



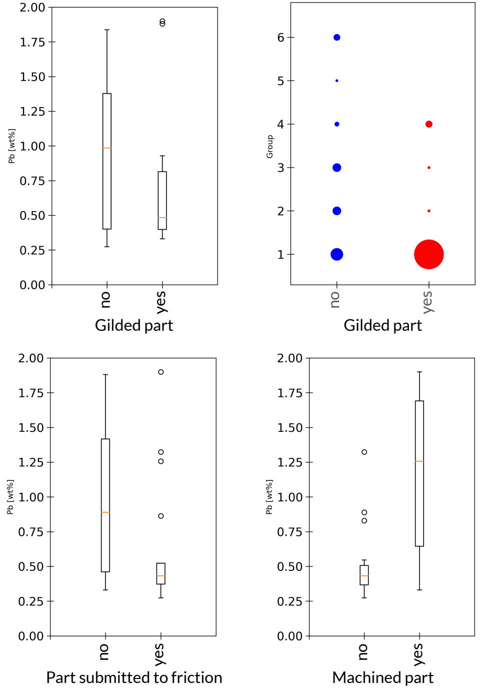



[10] [8] de la Vega, F., "Méthodes de classification automatique en archéologie", *in Archéologie et calcul*, Union générale d'éditions, 1978
[11] [9] Clarke, D.C., 1968. *Analytical Archaeology*. Methuen & Co Ltd, London

Projet Simon Le Noir

# Characterize the materials

- Groups of parts and concentrations of brass components can be compared with their aesthetic and functional characteristics
  → **multifactorial analysis and ANOVA tests** to quantify the influence of a parameter and understand the criteria used by clockmakers to select the brass they used
- Some examples:
  - on the Le Noir mechanism, gilded parts are most of the time made from low-lead brass whereas non-gilded parts contain lead in varying quantities (see top right figures)
    → probable use of low-lead brass to avoid the formation of dots under the gilding [12]
  - when not gilded, machined parts contain more lead than average (see bottom right figure)
    → the addition of lead makes brass more "machinable" and facilitates the cutting of the teeth (a similar strategy is observed on wheels made of steel, which contain less carbon than arbors or springs [13])




[12] [10] Theophilus, Hawthorne, J.G., Smith, C.S., 2022. *On Divers Arts*. Dover Publications, New York
[13] [11] Wayman, M.L. (Ed.), 2000. *The Ferrous Metallurgy of Early Clocks and Watches*. Occasional Paper 136. British Museum, London

# ArcheHor: Archeometry for Horology

- The Simon Le Noir Project focuses on the Le Noir mechanism but analysis of this mechanism alone is futile in the absence of points of comparison → very little data exists in the literature, **clockmaking has rarely been studied from an archaeological and scientific point of view**
- With this in mind, two other mechanisms were analysed (Claude Raillard (attr.), c.1660-62 & Isaac Thuret, c.1670-75) → similarities identified between these mechanisms and the one of Le Noir, particularly in the composition of the brass, maybe from the same supplier?
- The few other published data (brass compositions of British and German clocks from the 16th, 17th & 18th centuries) show significant dispersions → trends difficult to identify over a wide spatio-temporal interval
- Need to gather more data to refine analyses and derive relevant trends

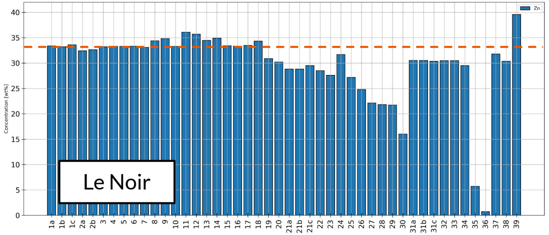
→ **ArcheHor's objectives: to systematise the scientific analysis of antique clocks** in order to build up a **large database** that will make it possible to **characterise the development of manufacturing techniques, the choice of materials, aesthetic conventions, *etc*.**, depending on the period and the country, in relation to technological progress and the changing role of clockmaking in a constantly evolving social, economic and political context

→ **several tasks derive from these objectives**

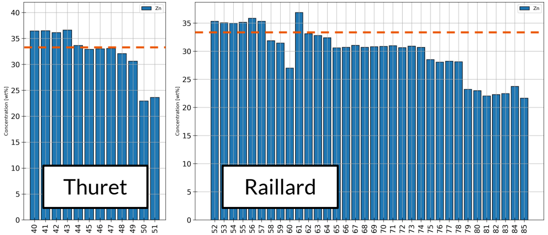
# Task 1: build a large database

- Without an existing, large database, the interpretation of data gathered on isolated artefacts is difficult, and it is impossible to infer any standard practice
- <u>One example of difficulty encountered</u> :
  - The brasses found in the Le Noir mechanism have high zinc contents, around 33%, and several parts exceed this limit → by using the classical *terminus pre quem* criteria known for brass, these parts should be considered apocryphal
  - By comparison, in scientific instruments, zinc content above 33% is very rarely observed [14]
  - However, the analyses of two other mechanisms from the same period (Raillard & Thuret) also show several parts made of brass with Zn > 33%

    → **generality of French clock mechanisms? Impossible to know in the absence of additional data**




*Zinc content – Le Noir*




*Zinc content – Thuret (left) & Raillard (right)*

[14] [12] Pollard, A.M., Heron, C., 2008. *Archaeological Chemistry – 2nd edition*. RCS Publishing, Cambridge

# Task 1: build a large database

- Sub-tasks to address to build a large, relevant database:

1. **Get access to artefacts to analyze**

   → museum collections (Musée du Louvre, Musée de Cluses...)? private collections?

2. **Having the necessary human resources and the right apparatus**
   - Until now, it has been the objects that have been moved for analysis, not the instruments
     → logic to be reversed, benefit of a mobile laboratory (Patrimex / MobiFlu / other)?
   - Human resources up to now provided "free of charge" by MNHN, Néel Institute and C2RMF
     → build a partnership for regular analyses? fund a master's degree / thesis?

3. **Define a generalisable, objective, reproducible operating protocol**

   → constraints: the parts analysed must be easily accessible, if possible without dismantling the mechanisms, they must be representative of the different types of brass in the mechanism and the different shaping processes (hammering, bending, machining), while limiting machine time = reduced number of measurement points BUT exhaustive enough to allow analysis of dispersions of secondary trace elements...

   → first protocol already tested on the Thuret mechanism based on results observed from Le Noir study

# Task 1: build a large database

4. **Gather all data from the literature**

   → matrix under construction to bring together available data on the analysis of materials used in clock mechanisms, across all chronological periods and geographical areas

   → few published data overall, particularly on the modern period (post-1600) and on brass

   → ask museums about analyses carried out in-house but not published?

5. **Structuring data and making it accessible**

   → use the HumaNum 3D consortium already used by CHRONOSPEDIA?

   → which format, in particular for raw XRF files?

   → possibility of searching for particular elements in the database, automatic generation of statistics, *etc.*

Ce tableau liste les analyses de composition élémentaire réalisées sur des pièces d'horlogerie.
Les lignes en orange concernent des objets qui sont en lien avec les mécanismes d'horlogerie mais qui ne sont ni des montres, ni des horloges.
Les lignes en rouge concernent des objets "suspects", pour lesquels l'authenticité n'est pas confirmée.

| Date / période (B.C.) | Dénomination | Fabricant | Origine | Matériau(x) analysé(s) | Collection | N° d'inventaire |
|---|---|---|---|---|---|---|
| **0-1500** | | | | | | |
| 400-600 | Astrolabe à roues dentées | inconnu | Empire Byzantin | laiton | Science Museum | 1983-1393 |
| **1500-1600** | | | | | | |
| 1530 | Montre de Philippe Mélanchthon | inconnu | Allemagne | laiton, dorure | Walters Art Museum | 58.17 |
| 1530 (c.) | Montre tambourin M49 | inconnu | Allemagne / France | laiton, acier | Museo Polid Pezzoli | Inv. 3395 cat 155 |
| 1540 (c.) | Montre tambourin M3 | inconnu | Allemagne | laiton | Walters Art Museum | 58.68 |
| 1550-1575 | Horloge de table | inconnu | Allemagne | acier | British Museum | CAI-3126 |
| 1570-1580 | Horloge de table | inconnu | Allemagne | acier | British Museum | 1901,0115.1 |
| **1600-1700** | | | | | | |
| 1600-1650 | Horloge - Sphère de Genève | inconnu | Japon | cuivre, laiton, plomb, dorure | Collection privée | n.a. |
| 1640 (c.) | Horloge de table | Johann Sayler (attr.) | Allemagne | acier | British Museum | 1981,0107.1 |
| 1645 | Pascaline du chancelier Séguier | inconnu (horloger rouennais ?) | France | laiton | Musée des Arts et Métiers | 19600-0000 |
| <1652 | Pascaline de Christine de Suède | inconnu (horloger rouennais ?) | France | laiton | Musée des Arts et Métiers | 00823-0001 |
| <1655 | Pascaline du chevalier Durant-Pascal | inconnu (horloger rouennais ?) | France | laiton | Muséum Henri Lecoq | 985-23 |
| <1655 | Pascaline de Marguerite Périer | inconnu (horloger rouennais ?) | France | laiton | Muséum Henri Lecoq | 138 |
| 1657 ? | Horloge murale | Jan van Call | Pays-Bas | laiton, acier, dorure | Science Museum | ? |
| 1658 ? | Horloge de table | Simon Le Noir | France | laiton, bronze, acier, dorure, soudure | Collection privée | n.a. |
| 1660-1662 | Horloge de table | Claude Raillard (attr.) | France | laiton, acier | Collection privée | n.a. |
| 1670-1675 | Horloge de table | Isaac Thuret | France | laiton, dorure | Collection privée | n.a. |
| 1660-1680 | Horloge de table | Johan Scheirer | Allemagne | laiton, verre, dorure, argenture, huile, résine, soudure | Buffalo Museum of Science | C12920 |
| **1700-1800** | | | | | | |
| 1709 | Horloge de table | Thomas Tompion | Angleterre | laiton | Collection privée | n.a. |
| 1722 | Horloge de table | George Graham | Angleterre | laiton | Collection privée | n.a. |
| 1730-1735 | Horloge marine H1 | John Harrison | Angleterre | laiton, bronze | Royal Museums Greenwich | ZAA0034 |
| 1737-1739 | Horloge marine H2 | John Harrison | Angleterre | laiton, bronze | Royal Museums Greenwich | ZAA0035 |
| 1740-1759 | Horloge marine H3 | John Harrison | Angleterre | laiton, bronze | Royal Museums Greenwich | ZAA0036 |
| 1747 | Horloge murale cartel "Cressent" | Jean-Baptiste Hervé (horloger) | France | laiton | Mairie de Marseille | n.a. |
| 1760-1770 | Montre | G. Taylor | Angleterre | laiton, dorure | Collection privée | n.a. |
| 1700-1800 | Horloge lanterne | | Pays-Bas ? | laiton | Musée International d'Horlogerie de La Chaux-de-Fonds | |
| **1800-1900** | | | | | | |
| 1828 | Montre - spiral | James Scrymgeour | Angleterre | verre | British Museum | 1958,1006.3073 |
| 1836 | Montre - spiral | Edward Dent | Angleterre | verre | British Museum | 1958,1006.3394 |
| 1835-1840 | Montre - spiral | Edward Dent | Angleterre | verre | British Museum | 1958,1006.3009 |
| **1900-2000** | | | | | | |
| 1929 | Montre marine | Thomas Mercer | Angleterre | or | Collection privée | n.a. |
| 1930-1955 ? | Horloge régulateur | Louis Leroy (ateliers) | France | acier | Collection privée | n.a. |
| 1931-1934 | Horloge de table "Uniclok" | Universal Clock and Globe Corp | Etats-Unis | laiton, zinc, plastique | Buffalo Museum of Science | |

*Matrix of the analyses from the literature for ArcheHor*

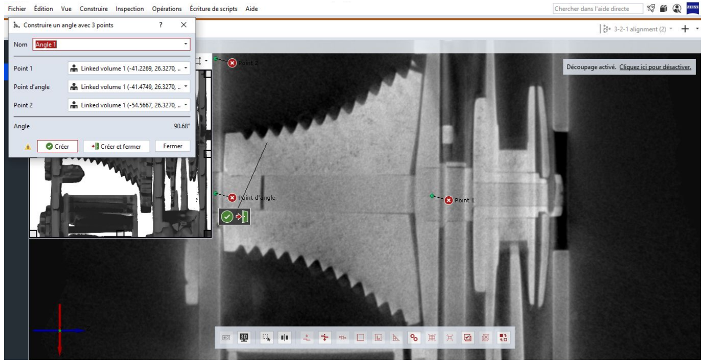
# Task 2: refine the existing analyses

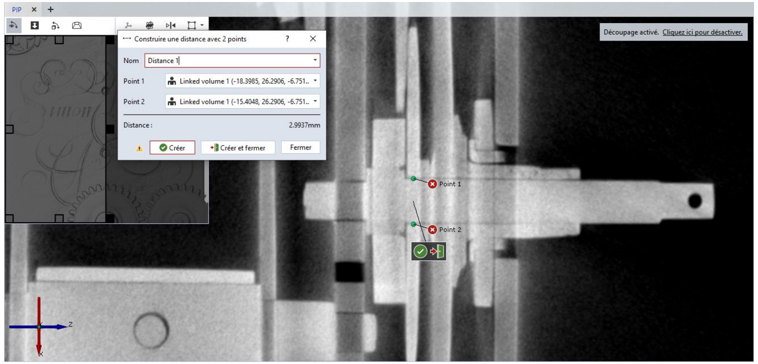
- In order to "increase" the data already available on the Le Noir mechanism, other methods of analysis could be used to further characterise the materials used by clockmakers and understand the associated manufacturing techniques
- Scientific analysis techniques used to date:
  - elemental composition: SEM-EDX (steel, brass, gilding, soldering, surface impurities and oxidation), ED-XRF (steel, brass, gilding, soldering), PIXE (brass, gilding)
  - detailed visualisation: SEM (surface views), X-ray tomography
- Other techniques of analysis identified that may be relevant:
  - **XRD (SOLEIL PUMA line?)** → identification of shaping technique (*e.g.* hammering *vs.* rolling) [15]
  - **(LA-)ICP-MS (C2RMF?)** → analysis of lead isotopes contained in brass to characterise its geographical origin? identification of secondary trace elements as indicators of origin? analysis of impurities in crucible steels to identify a production workshop?...
  - **DNA** → animal origin of the rope linking the barrel to the fusee
- **Experimental archaeology may be very useful** to reproduce the manufacturing techniques using the same tools and constraints as 17th-century clockmakers, to gain a better understanding of their approach and the choices they made when manufacturing a mechanism

[15] [13] Stephenson, G.B., Stephenson, B., Haeffner, D.R., 2001. *Investigations of Astrolabe Metallurgy Using Synchrotron Radiation.* MRS Bulletin 26 (1), pp. 19-23

# Task 3: preserve the data for future studies

- Some data is already available in a generic format that is *a priori* permanent (.txt for example)
- Other data is in a proprietary format, linked to the device that generated it, *e.g.* tomography scans produced by Zeiss that can only be read with the ZEISS INSPECT software (below)




- If the Zeiss software were to become obsolete, the tomography scans could no longer be read
  → dramatic loss of information, hence the need to find a way of converting the original files into a permanent format
- → topic being studied by CHRONOSPEDIA with the HumaNum 3D consortium and LS2N

# Bibliography

References by order of citation:


1. Gomand, A., 2022. *Simon Le Noir et l'application du pendule aux horloges : une histoire parallèle ?* Horlogerie Ancienne 91, pp. 16-44
2. Gomand, A., 2023. *Compléments dans l'affaire Simon Le Noir*. Horlogerie Ancienne 93, pp. 16-42
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Except the figures of slide 2 (from CHRONOSPEDIA), all other figures are from the author.