Young Minds - 27 février 2023

De la chaleur obscure aux jumeaux digitaux

Retour sur 200 ans de connaissances en sciences du climat

François Massonnet
francois.massonnet@uclouvain.be
@FMassonnet
www.climate.be/u/fmasson


COVID-19 SCIENCE
AS LONG AS WE JUST PROVIDE THE FACTS TO THE AMERICAN PEOPLE

2020

Etienne Klein

« Aujourd'hui, on a tous beaucoup de connaissances scientifiques, [...] plus que toutes les générations passées.

... tout le monde sait que l'atome existe ...

... tout le monde sait que l'univers est en expansion ...

... tout le monde sait que la Terre est ronde.

Mais personne ne sait comment on l'a su.

Nous traitons nos connaissances comme des croyances »

https://www.youtube.com/watch?v=mMJDcyEGbcg

« Qui aurait pu prédire la crise climatique? »

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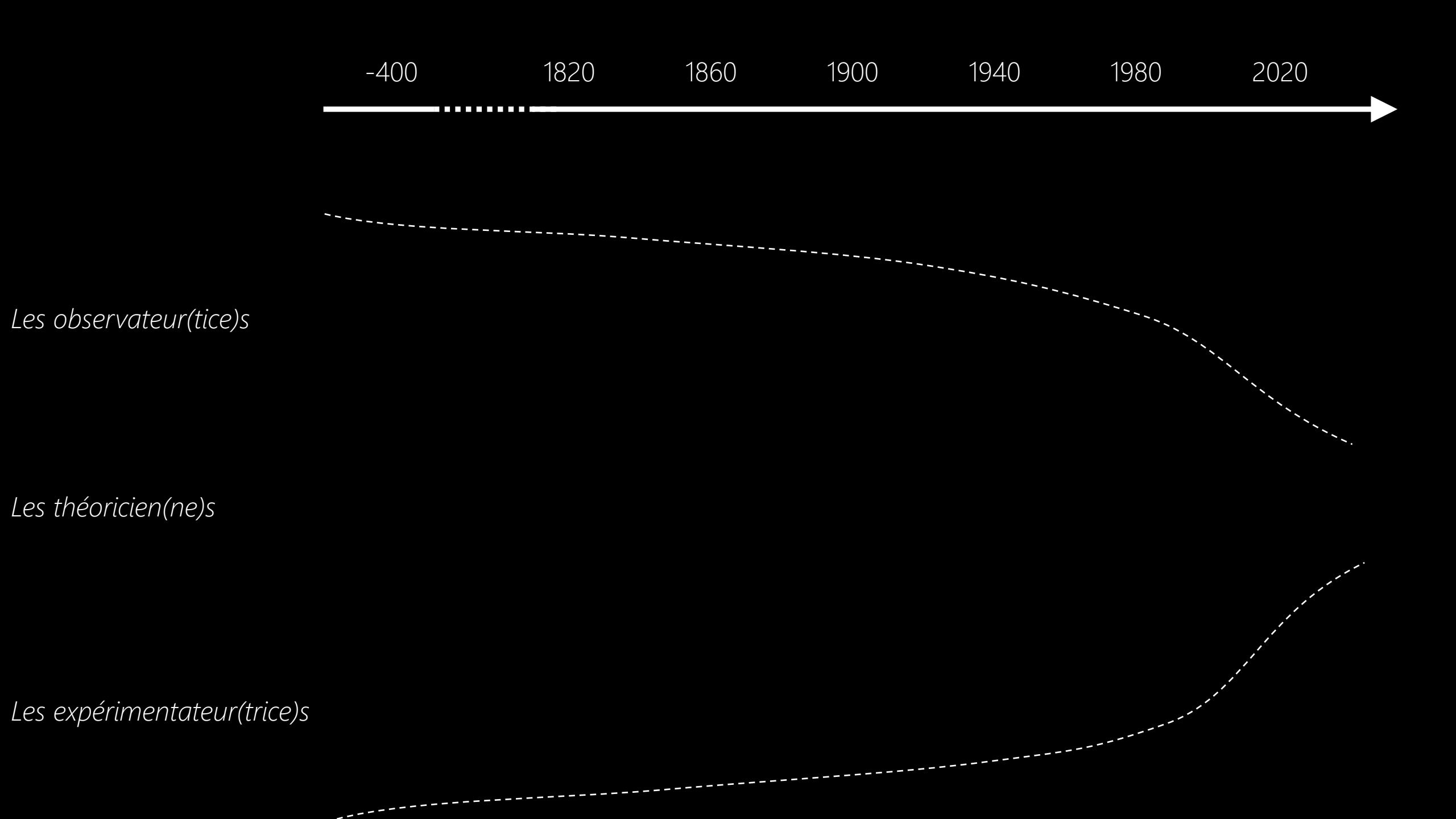
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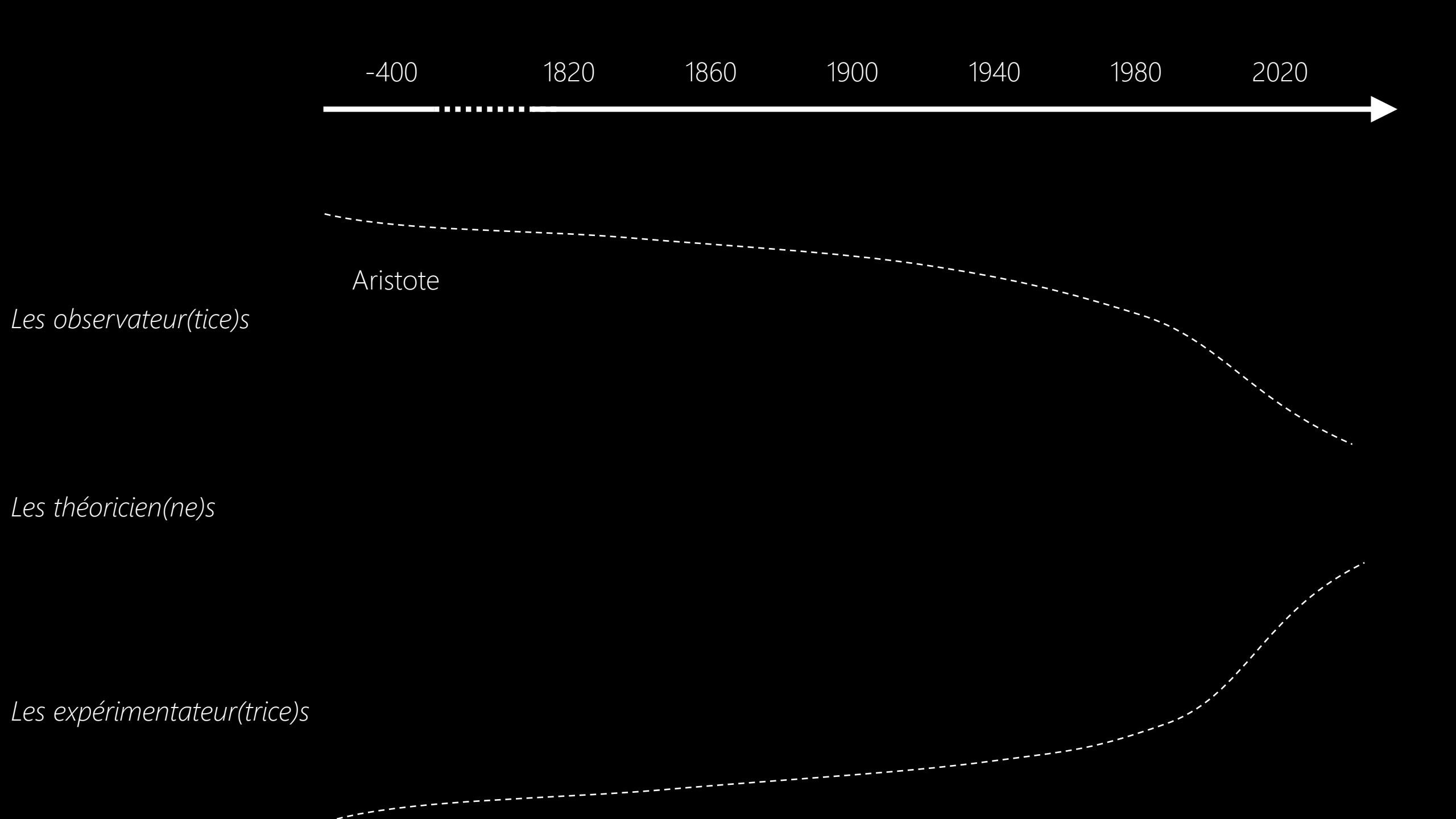
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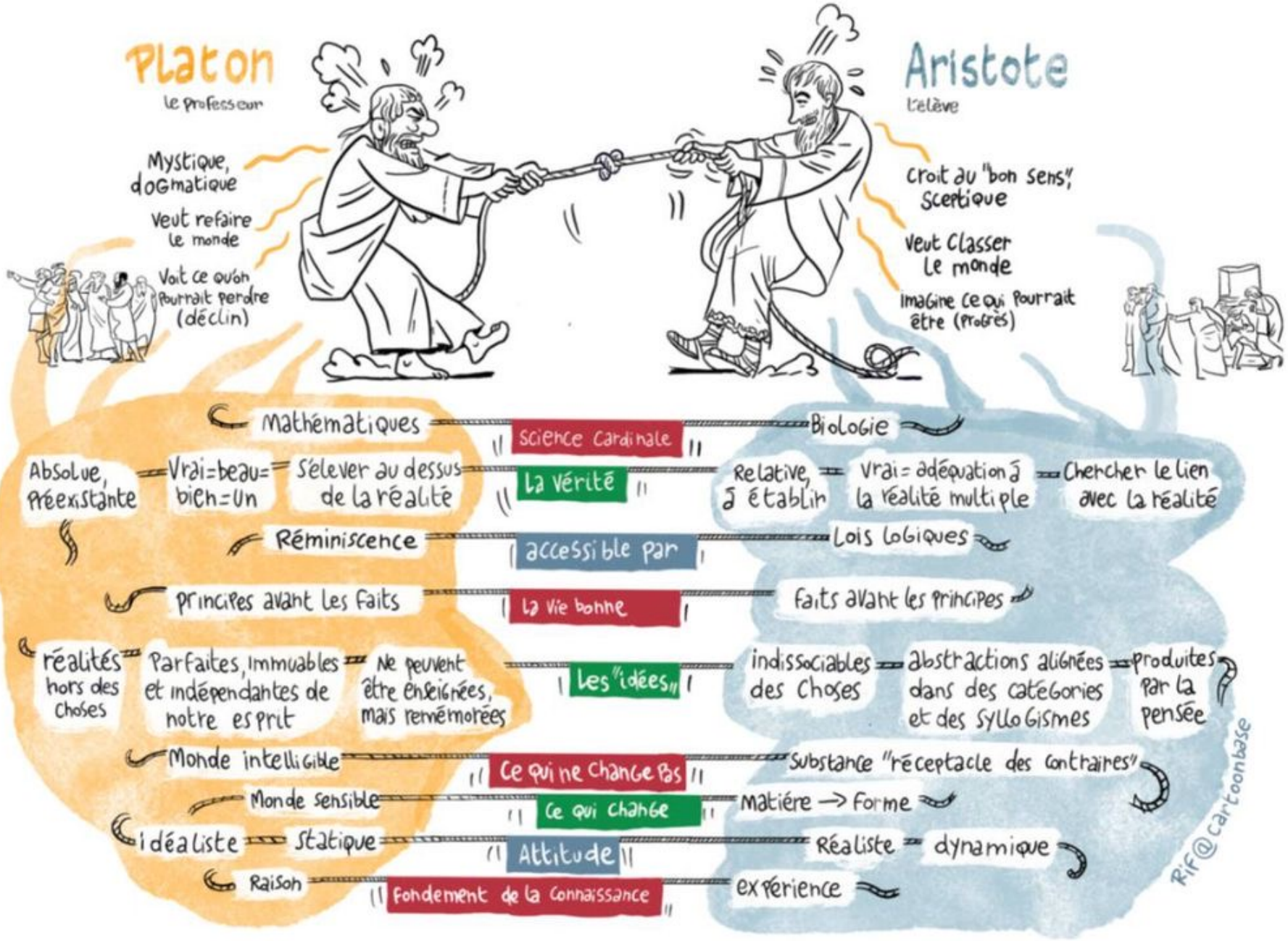
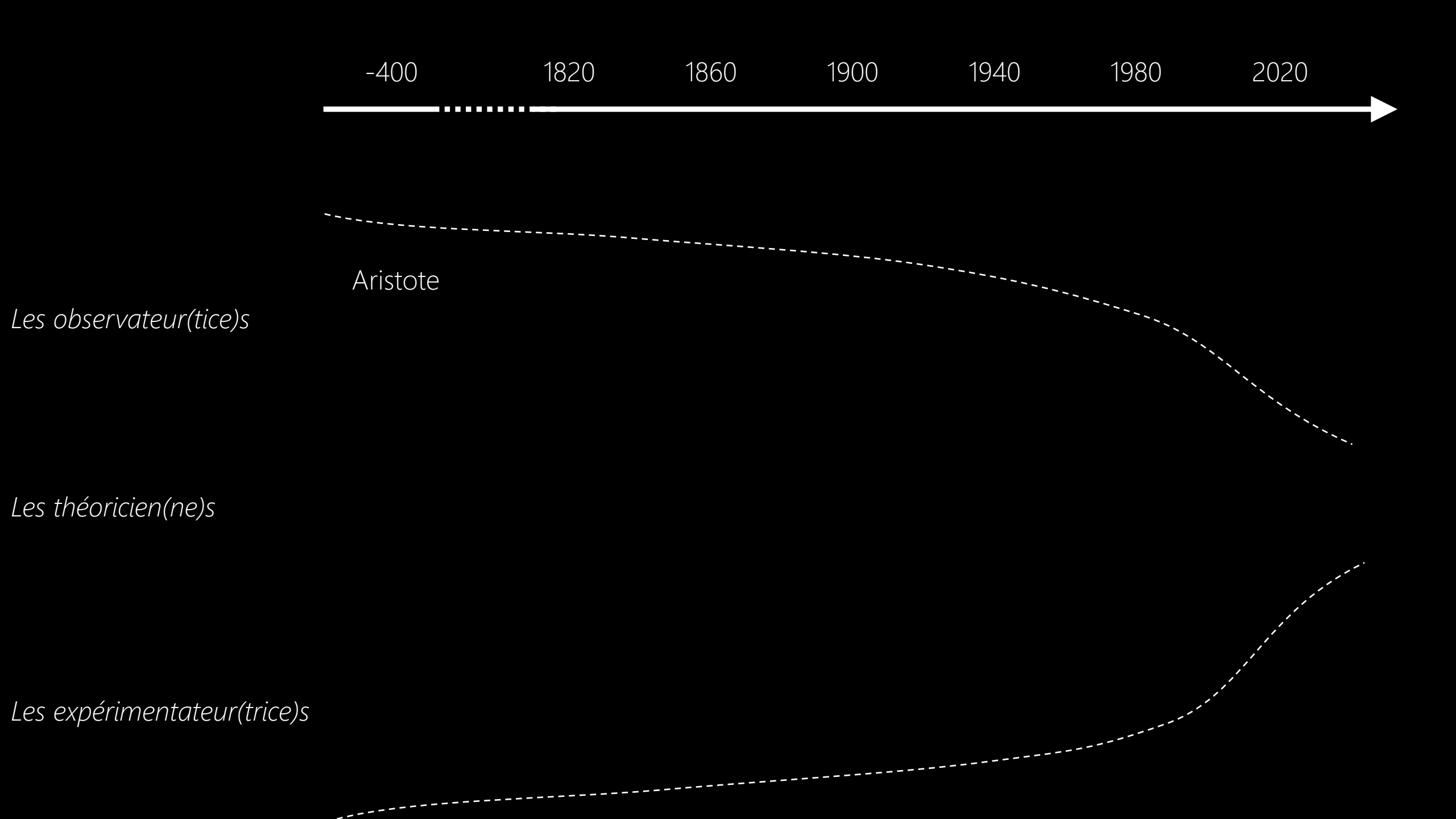
Aristote (384-382 av. J. -C.)



De Brabandere, L., Mikolajczak, A., & Rif, V. (2021). Platon vs Aristote: Une initiation joyeuse à la controverse philosophique. Sciences humaines éditions.

κλίμα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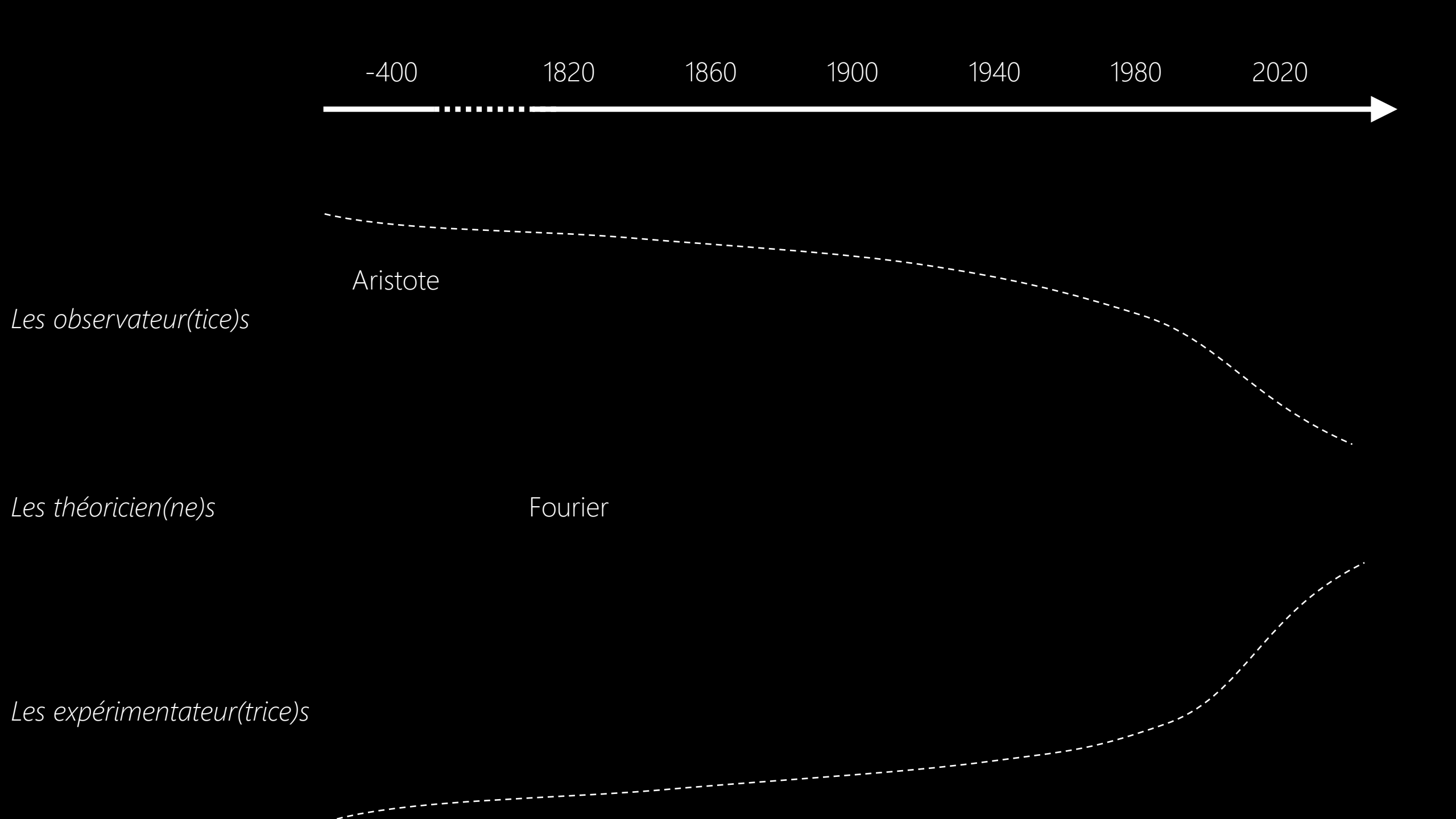
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Les expérimentateur(trice)s

Joseph Fourier (1768-1830)

MÉMOIRE

SUR

LES TEMPÉRATURES DU GLOBE TERRESTRE ET DES ESPACES PLANÉTAIRES.

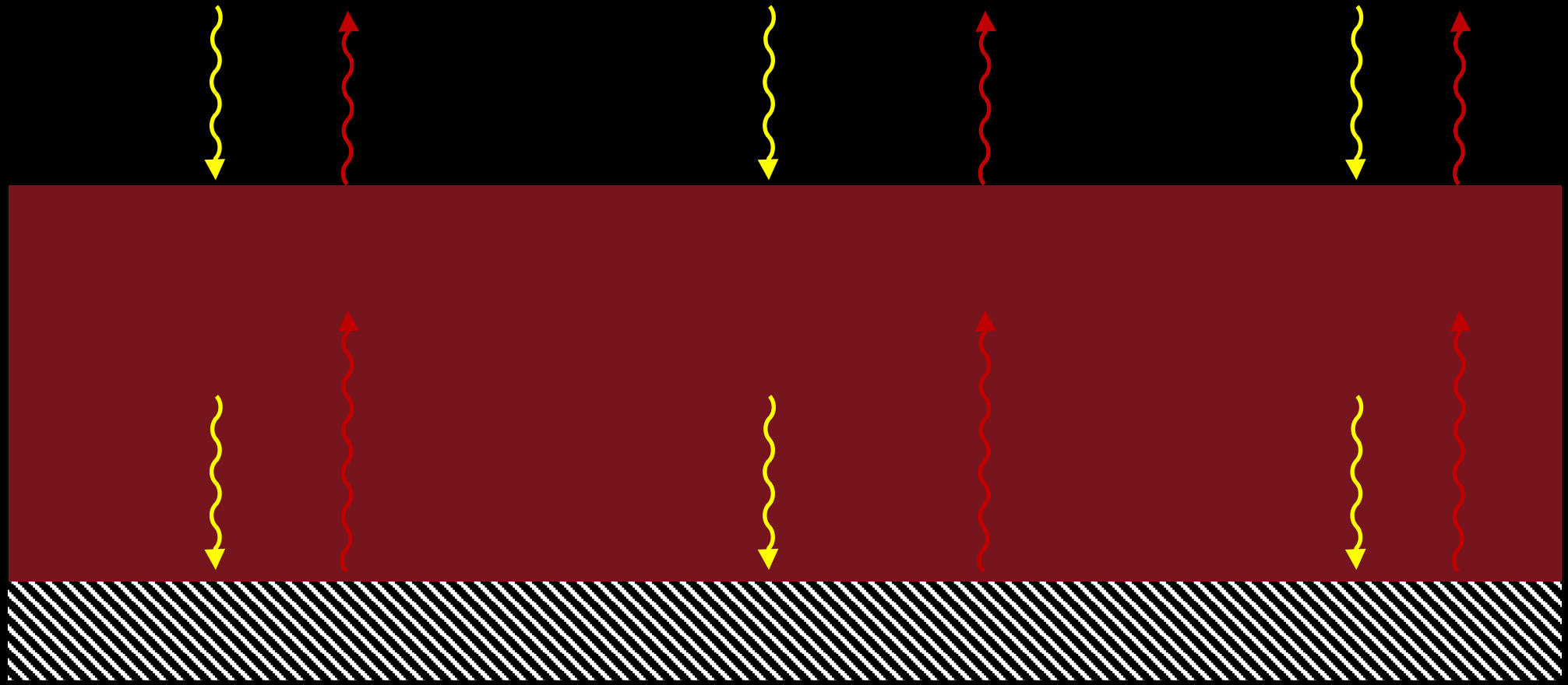
PAR M. FOURIER.

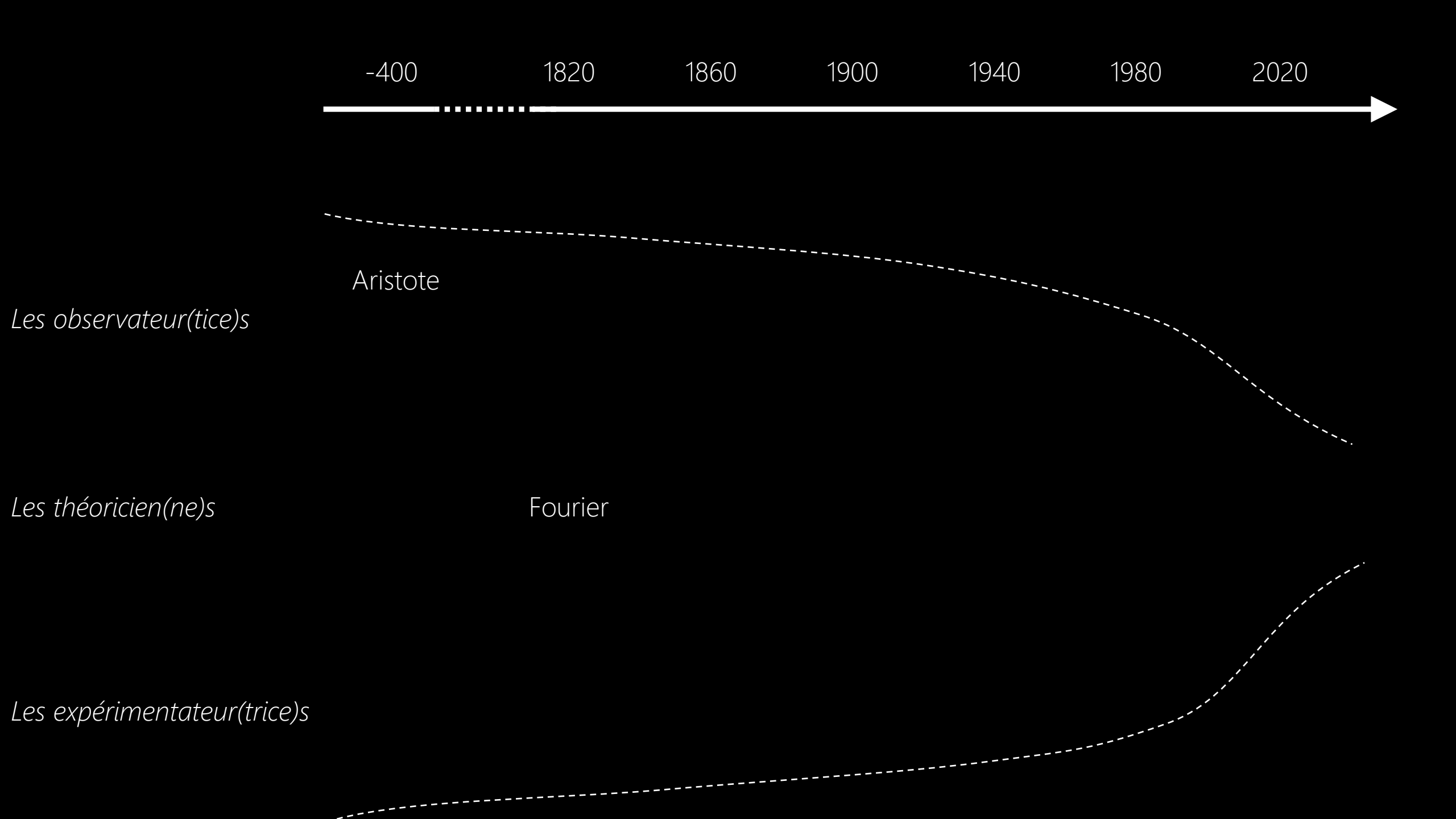
LA question des températures terrestres, l'une des plus importantes et des plus difficiles de toute la philosophie naturelle, se compose d'éléments assez divers qui doivent être considérés sous un point de vue général. J'ai pensé qu'il serait utile de réunir dans un seul écrit les conséquences principales de cette théorie; les détails analytiques que l'on

Fourier, J. (1827). Mémoire sur les températures du globe terrestre et des espaces planétaires. https://www.academie-sciences.fr/pdf/dossiers/Fourier/Fourier_pdf/Mem1827_p569_604.pdf

1824

« C'est ainsi que la température [de l'air] est augmentée par l'interposition de l'atmosphère, parce que la chaleur trouve **moins d'obstacle pour pénétrer l'air, étant à l'état de lumière,** qu'elle n'en trouve pour repasser dans l'air lorsqu'elle est convertie en chaleur obscure. »

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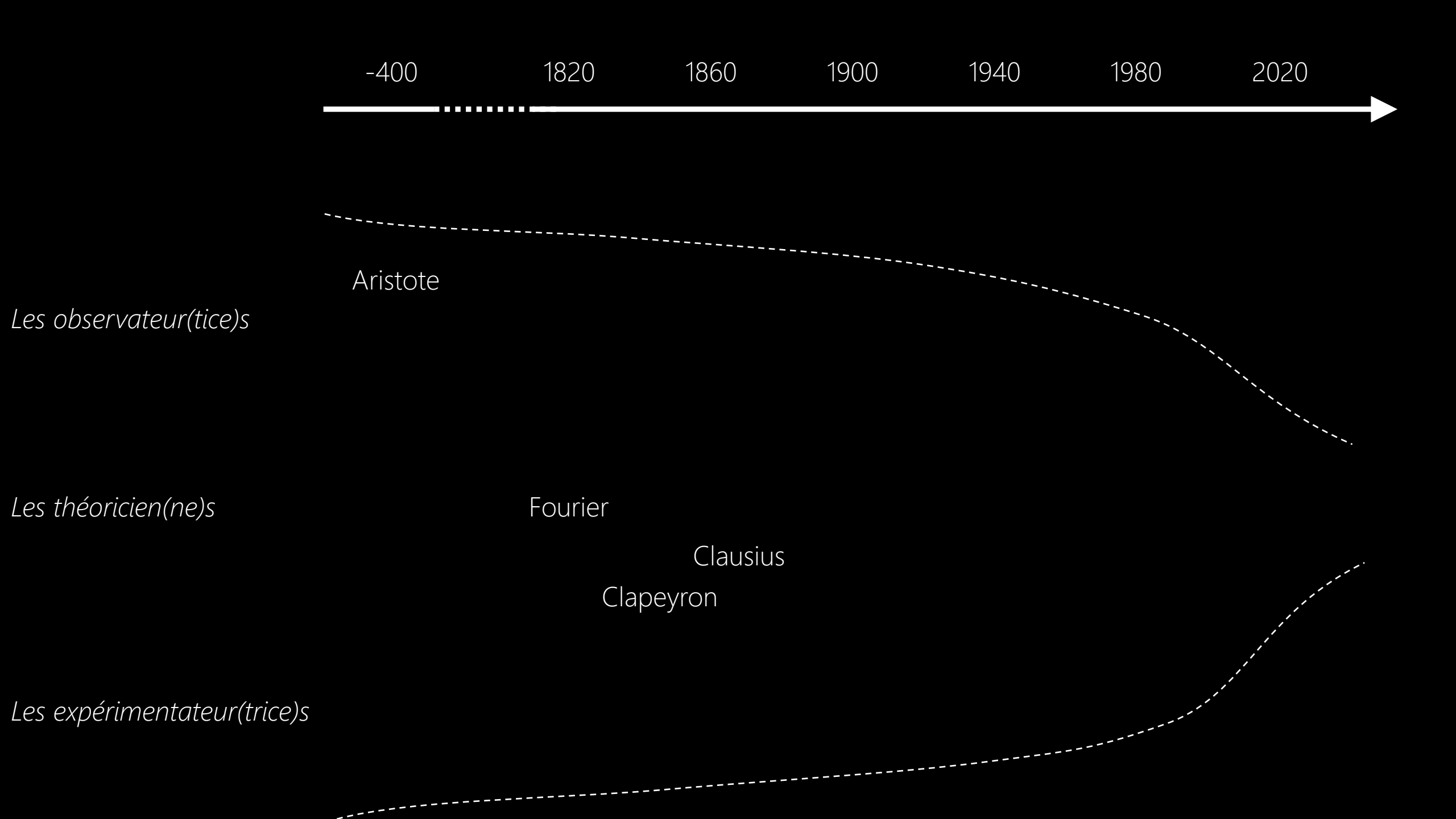
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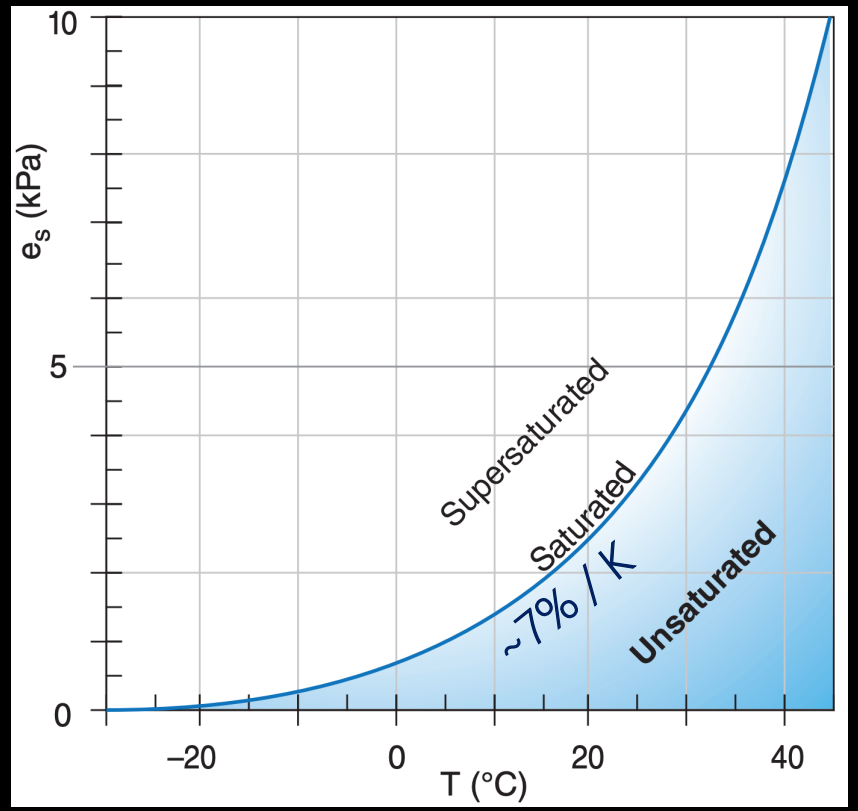
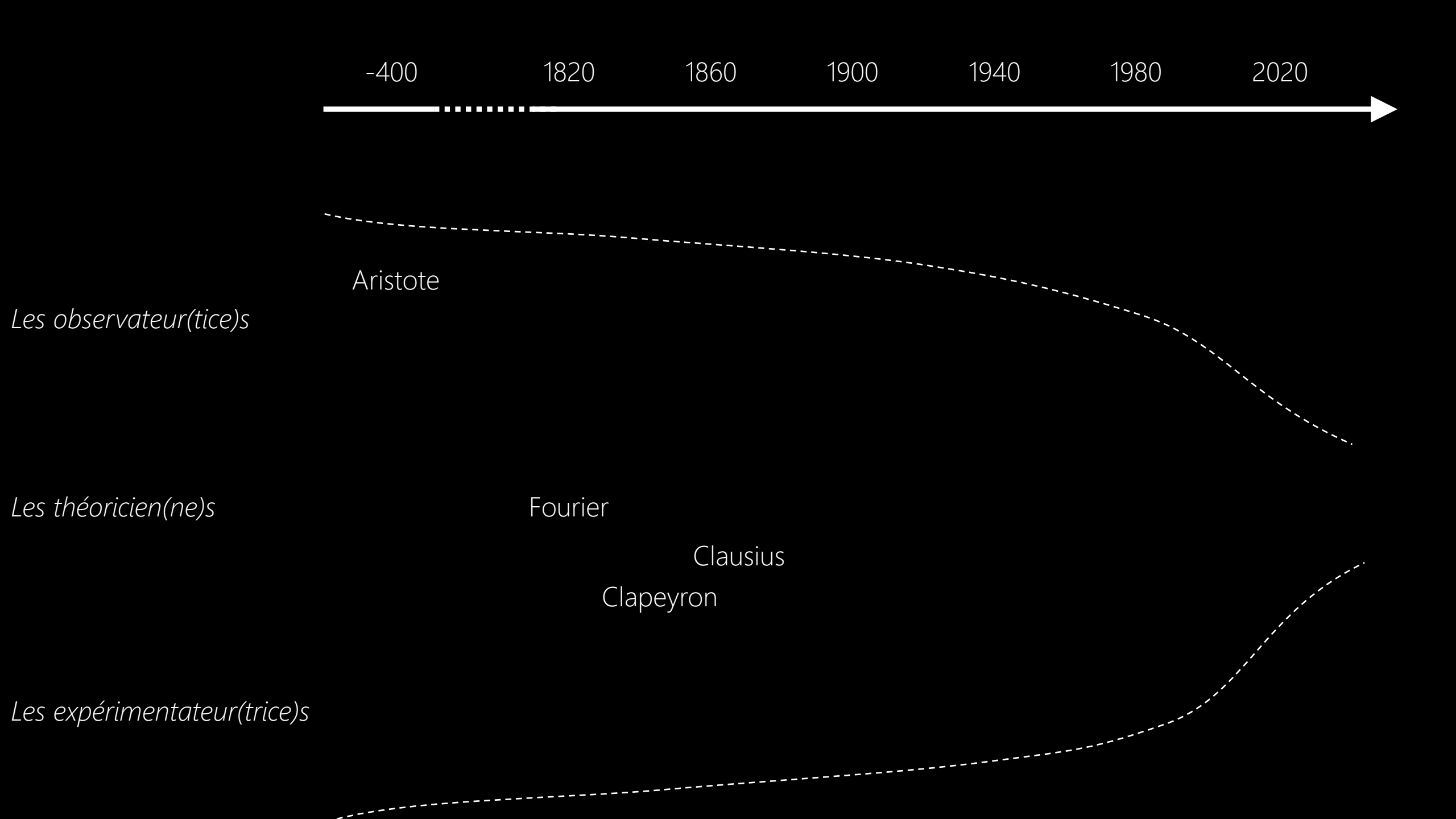
Emile Clapeyron
(1799-1864)

$$\frac{de_s}{dT} = \frac{L_{lv}\, e_s}{R_v\, T^2}$$

Rudolf Clausius
(1822-1888)



1834-1850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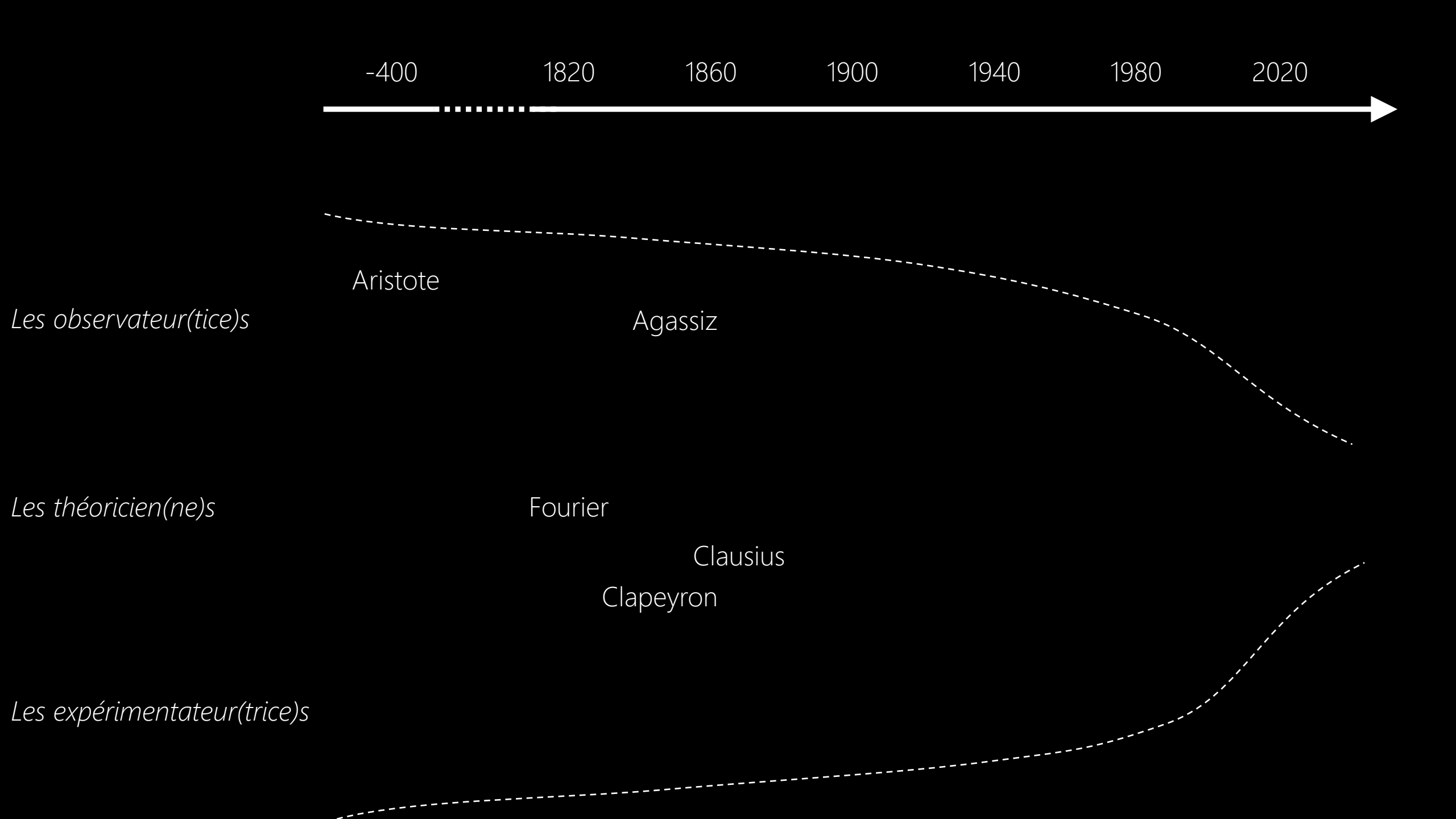
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Clapeyron
Les expérimentateur(trice)s

Louis Agassiz (1807-1873)

ÉTUDES

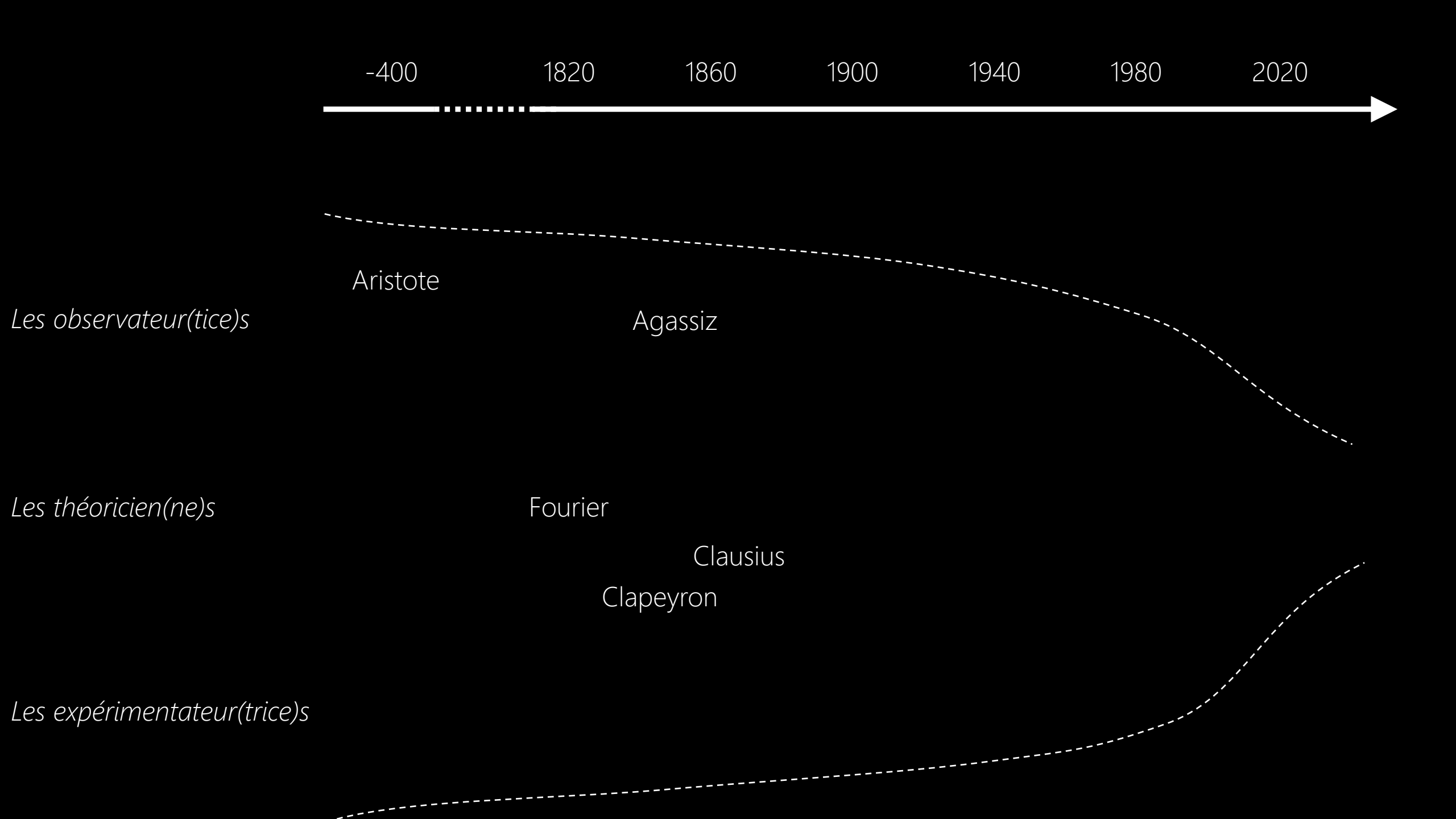
SUR

LES GLACIERS.

Agassiz, L. (1807-1873). (1840). Études sur les glaciers / par L. Agassiz. https://gallica.bnf.fr/ark:/12148/bpt6k105057x

1840

« Mes propres recherches avaient d'abord pour but principal de démontrer la liaison des phénomènes qui accompagnent les glaciers actuels avec les phénomènes analogues qui annoncent une plus grande extension des glaciers à une époque antérieure à la nôtre »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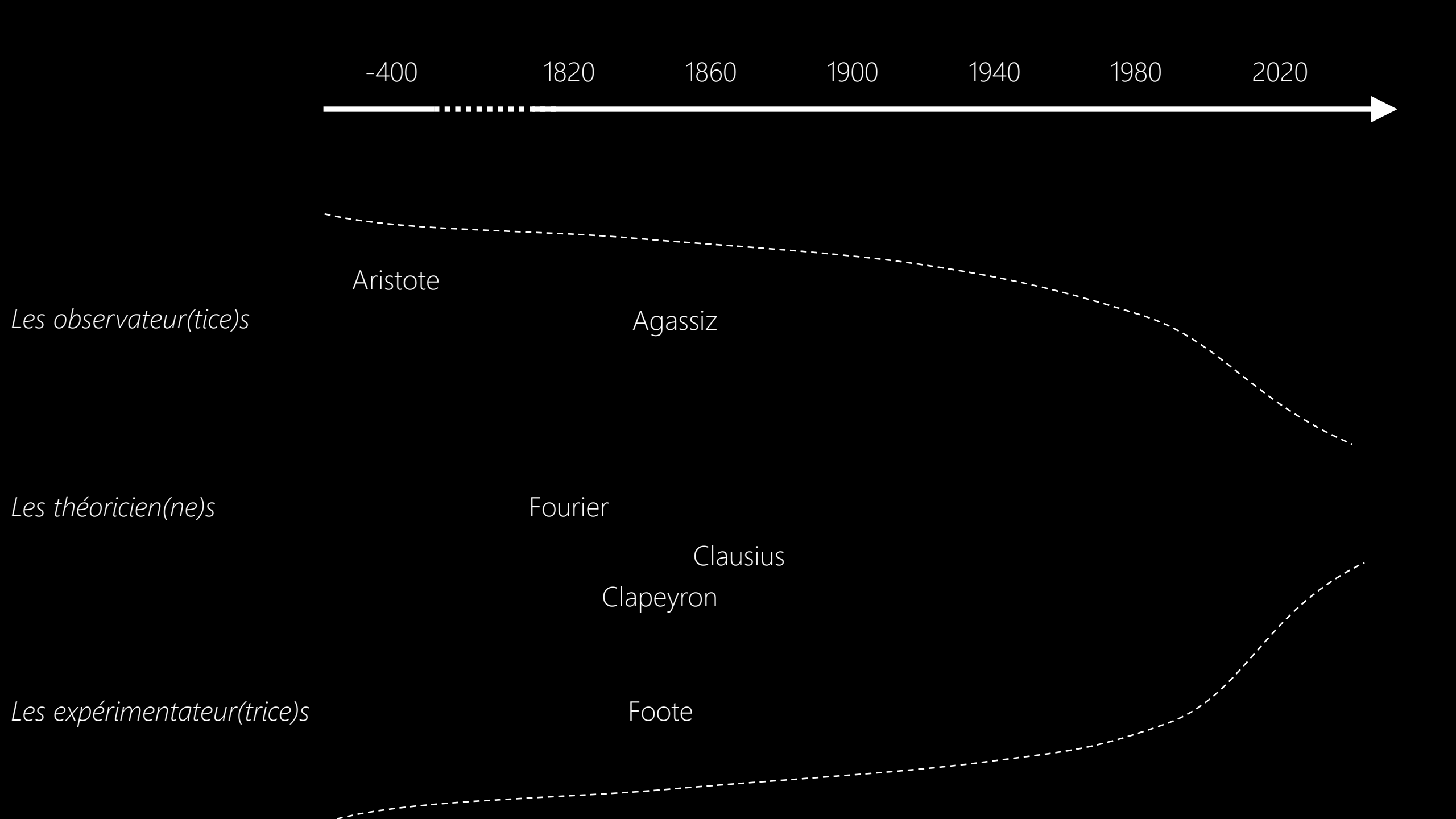
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Foote

Eunice Foote (1819-1888)

382 *On the Heat in the Sun's Rays.*

ART. XXXI.—*Circumstances affecting the Heat of the Sun's Rays;* by EUNICE FOOTE.

(Read before the American Association, August 23d, 1856.)

1856

Températures en °F

In Common Air.		In Carbonic Acid Gas.	
In shade.	In sun.	In shade.	In sun.
80	90	80	90
81	94	84	100
80	99	84	110
81	100	85	120

« Le récipient contenant le gaz [le CO_2] s'est lui-même beaucoup réchauffé - très sensiblement plus que l'autre [avec de l'air] - et lorsqu'on l'a retiré, il a mis plusieurs fois plus de temps à refroidir. »

Cloche à vide

Pompe à air

Matilda Effect

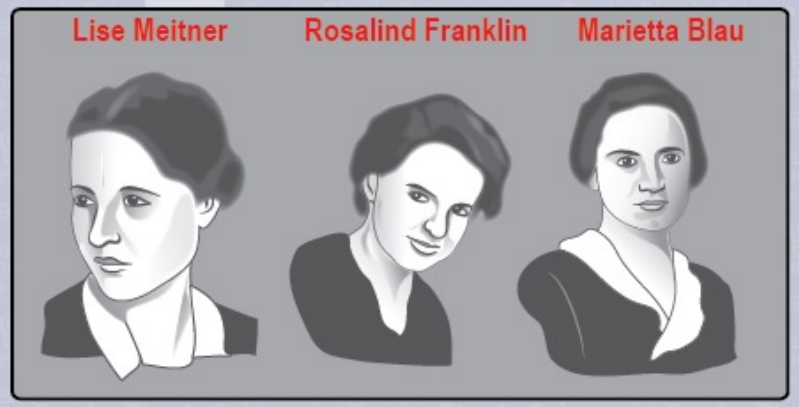
Denial of the contribution of women scientists in research
first described by Matilda Joslyn Gage

Mary is a female researcher working in an interesting field. She has got relevant ideas and has obtained promising results

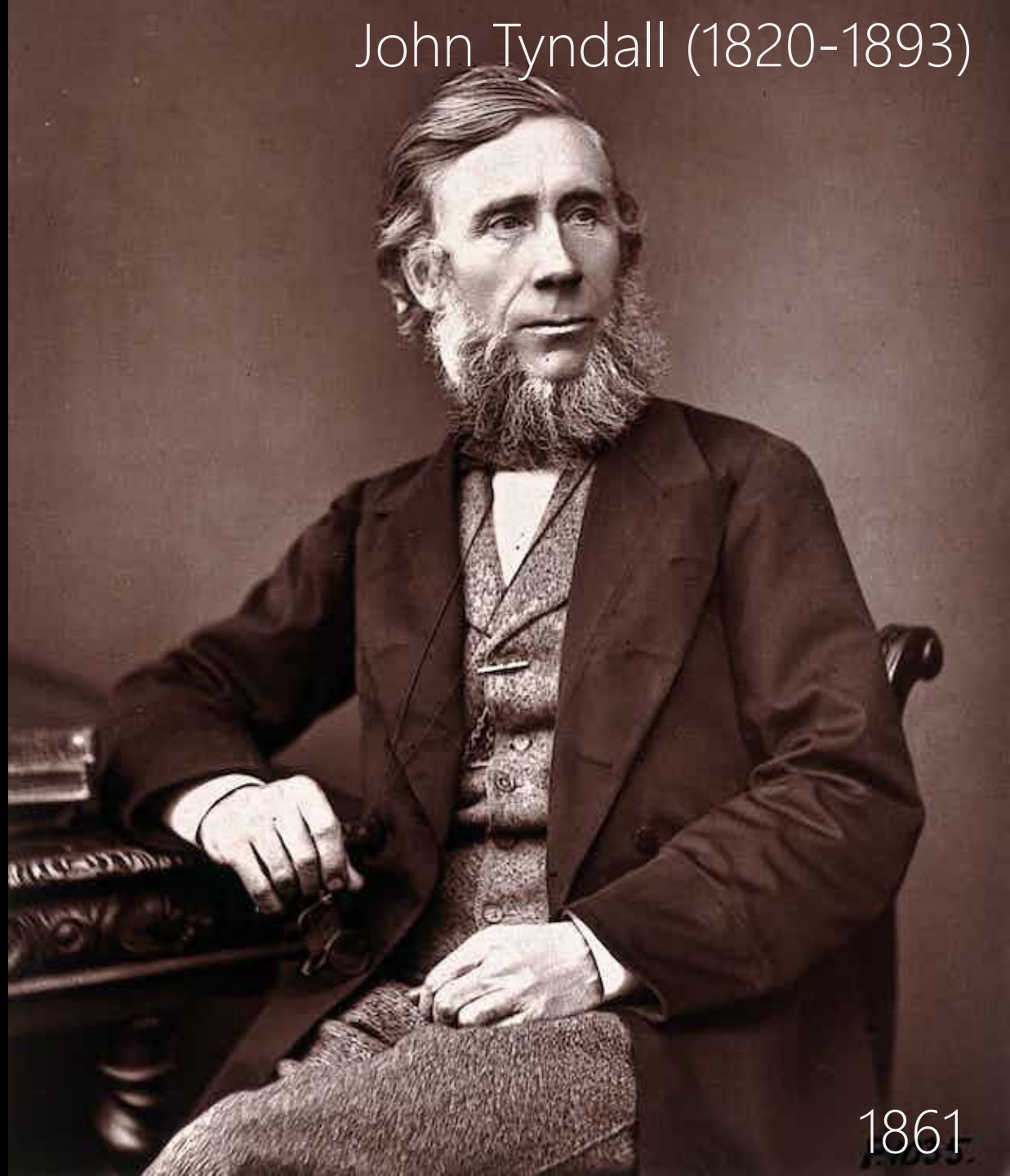
but

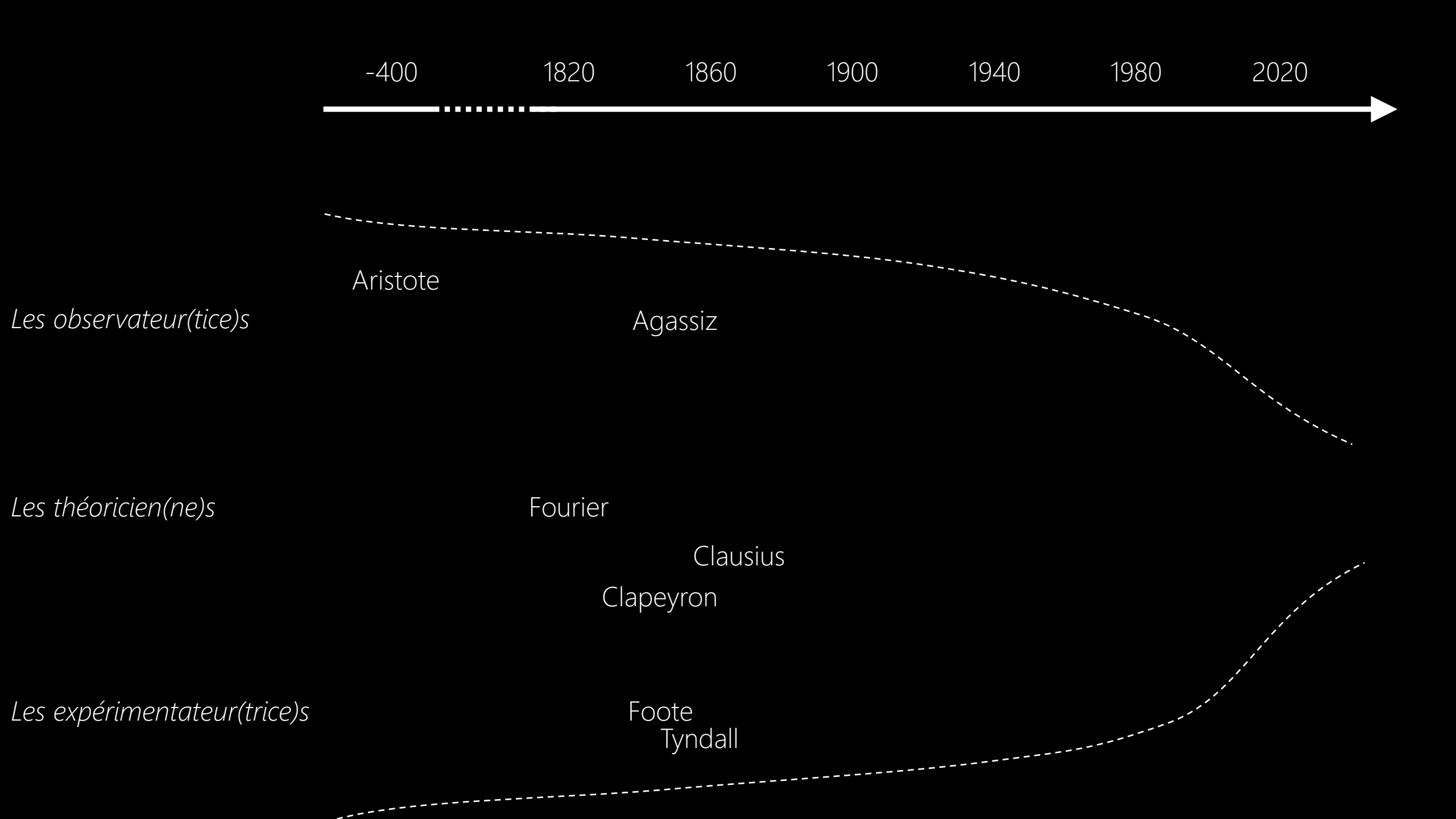
it is **Marc**, male fellow researcher in the same field, who is going to get the credit for Mary's work.

It happened to the work of such extraordinary female scientists as:



IlluScientia

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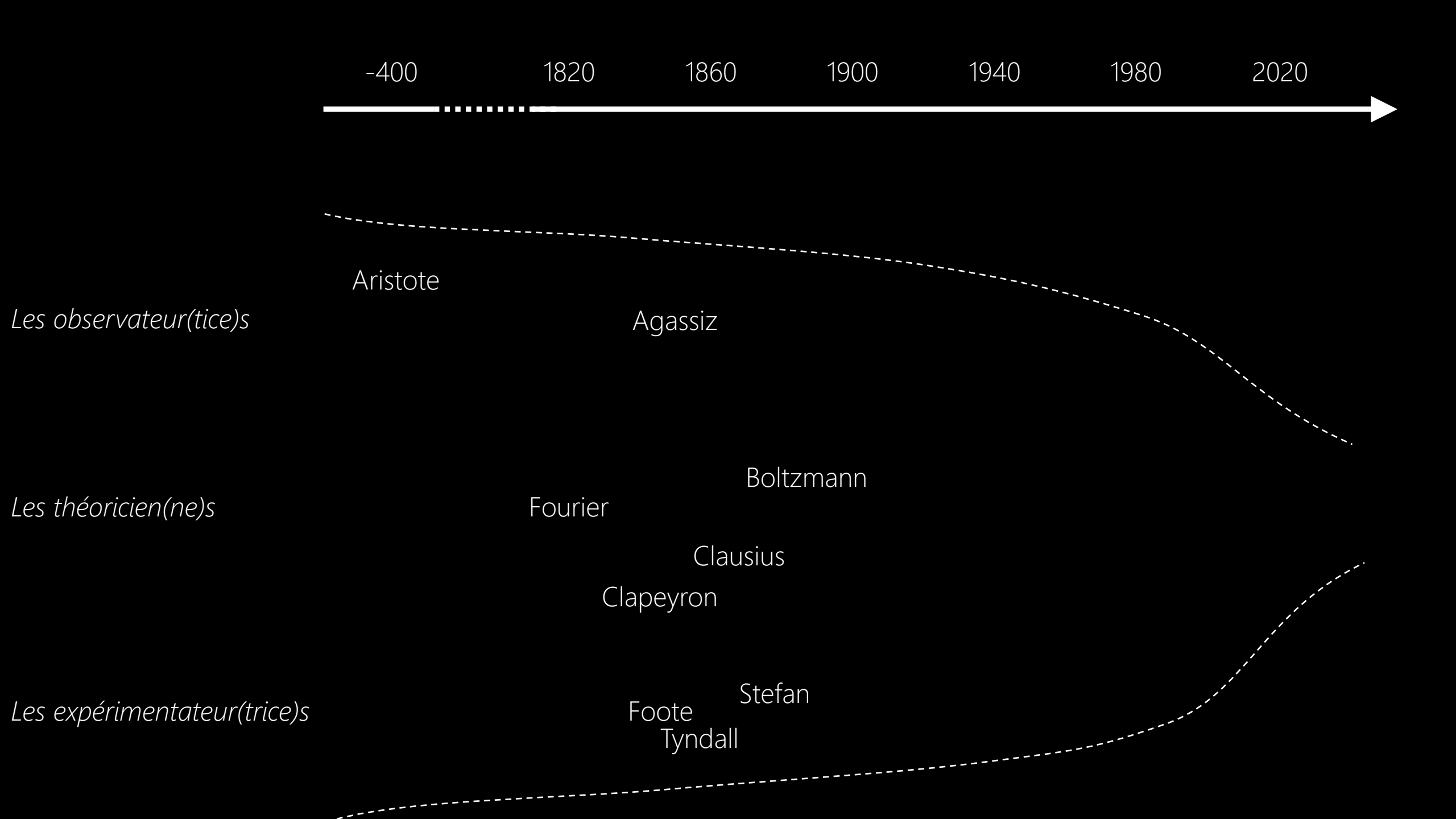
Foote
Tyndall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Foote
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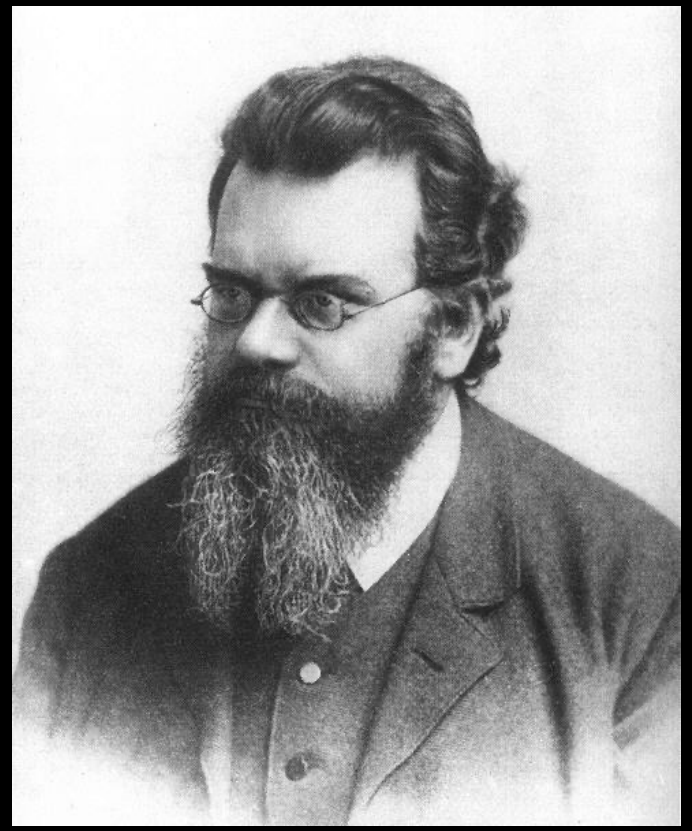
Loi de Stefan-Boltzmann

Jozef Stefan (1835-1893)

Ludwig Boltzmann (1844-1906)



aufgestellten Formel für dieselbe Grösse gefundene Zahl.

Um die von der Einheit der Glasfläche bei 100° ausgestrahlte Wärmemenge nach der neuen Formel zu berechnen, hat man 0·3475 mit $\left(\frac{373}{273}\right)^4 = (1{\cdot}366)^4$ zu multipliciren. Man erhält $AT_{100}^4 = 1{\cdot}2110$ und somit die Grösse

$$A(T_{100}^4 - T_0^4) = 0{\cdot}8635,$$

etwas kleiner als nach der Formel von Dulong und Petit.

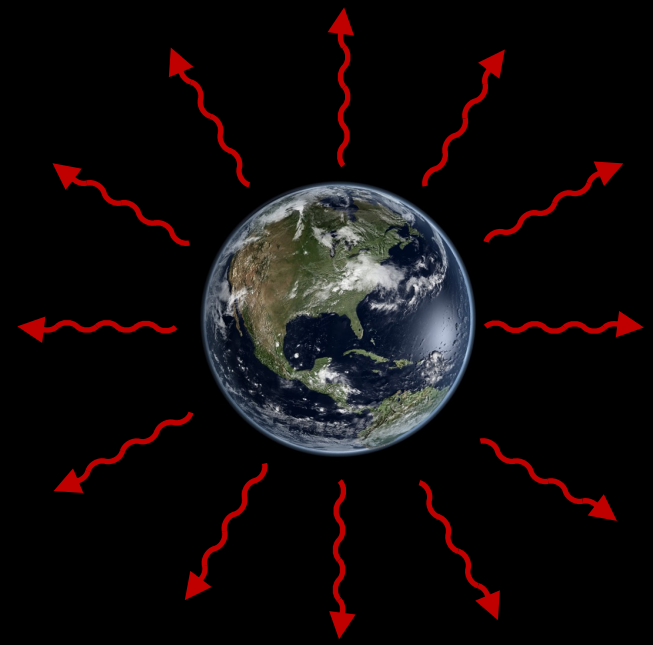
Durch Division mit 0·88 erhält man die auf eine schwarze

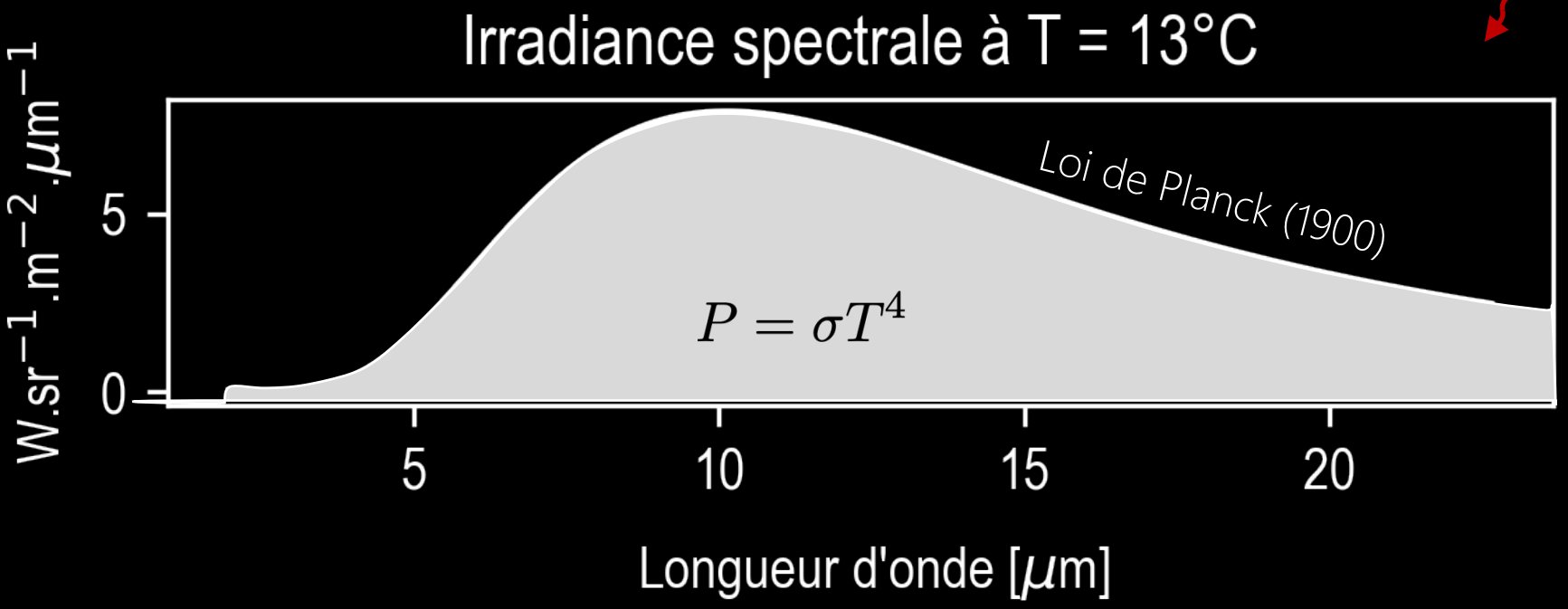
Stefan, J. (1879). Über die Beziehung zwischen der Wärmestrahlung und der Temperatur. http://www.ing-buero-ebel.de/strahlung/Original/Stefan1879.pdf

$$P = \sigma T^4$$

$$\sigma \approx 5.67 \times 10^{-8}\ \mathrm{W.m^{-2}.K^{-4}}$$

1879




Irradiance spectrale à T = 13°C
W.sr^{-1}.m^{-2}.μm^{-1}
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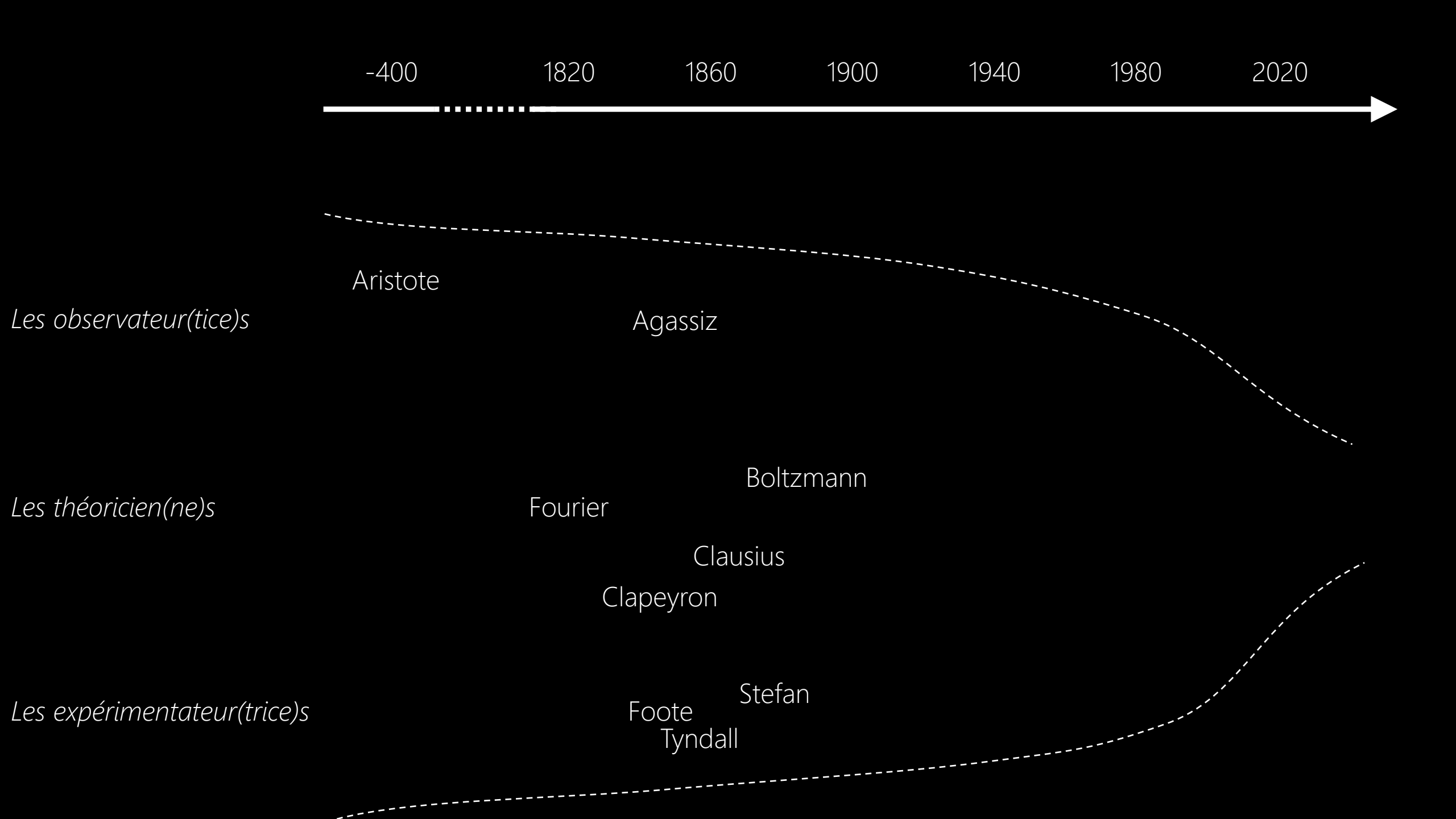
Longueur d'onde [μm]
Loi de Planck (1900)
$P = \sigma T^4$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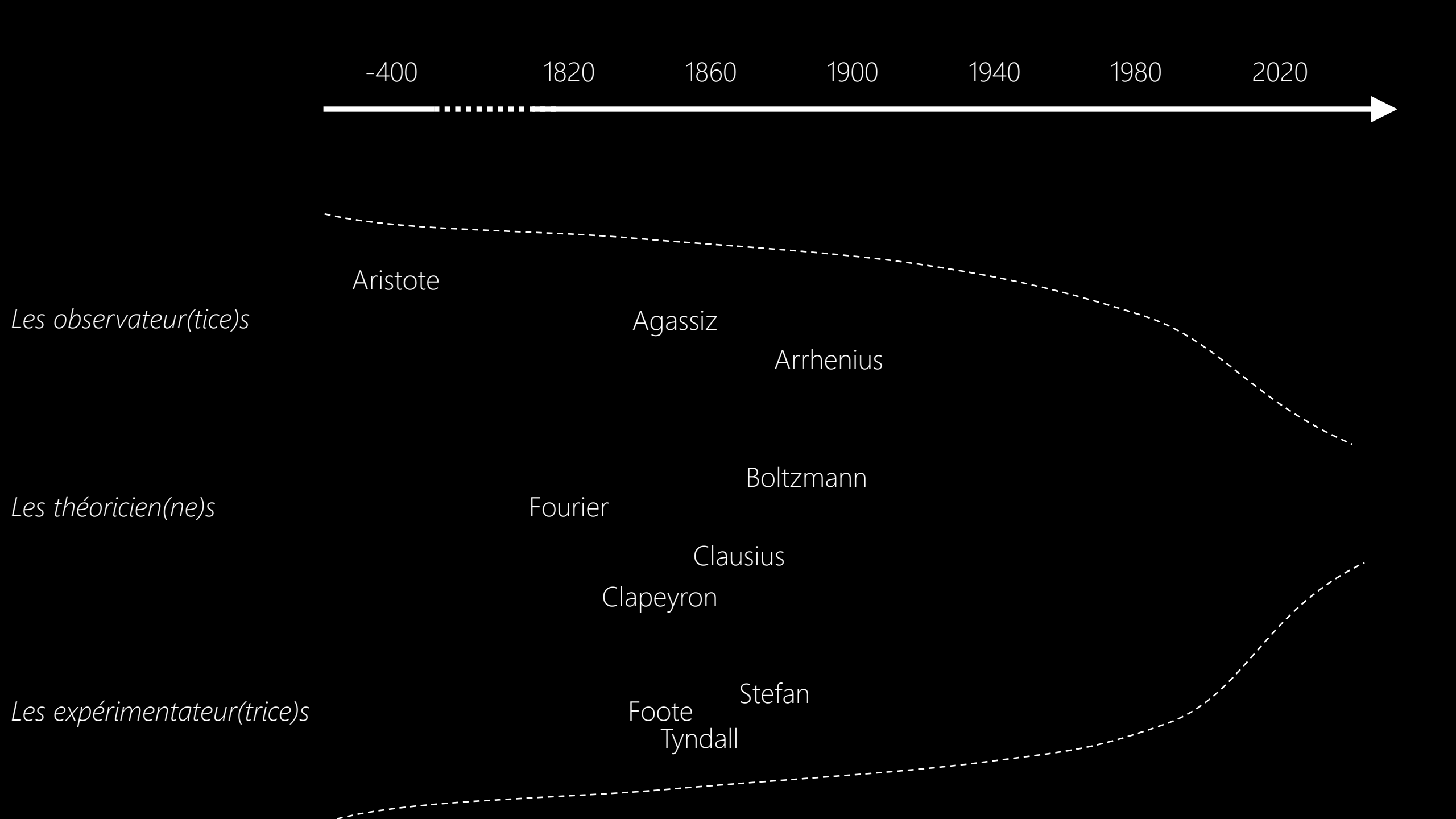
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Svante Arrhenius (1859-1927)

THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

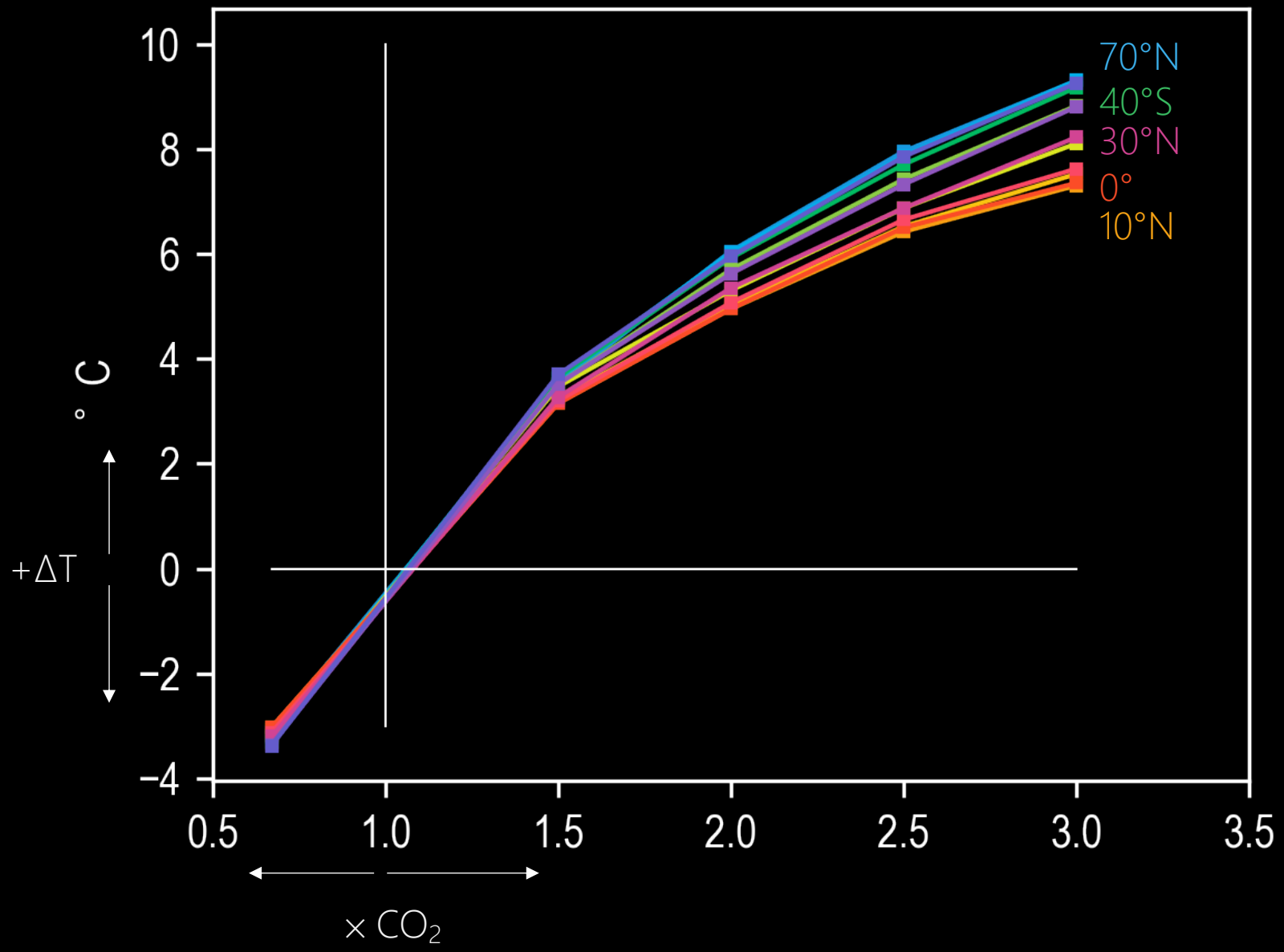
APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* *By* Prof. SVANTE ARRHENIUS *.

Arrhenius, S. (1896). On the influence of carbonic acid in the air upon the temperature of the ground. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 41(251), 237–276. https://doi.org/10.1080/14786449608620846

1896

Réponse estimée de la température de l'air à une multiplication de la concentration atmosphérique en CO_2



Relation logarithmique

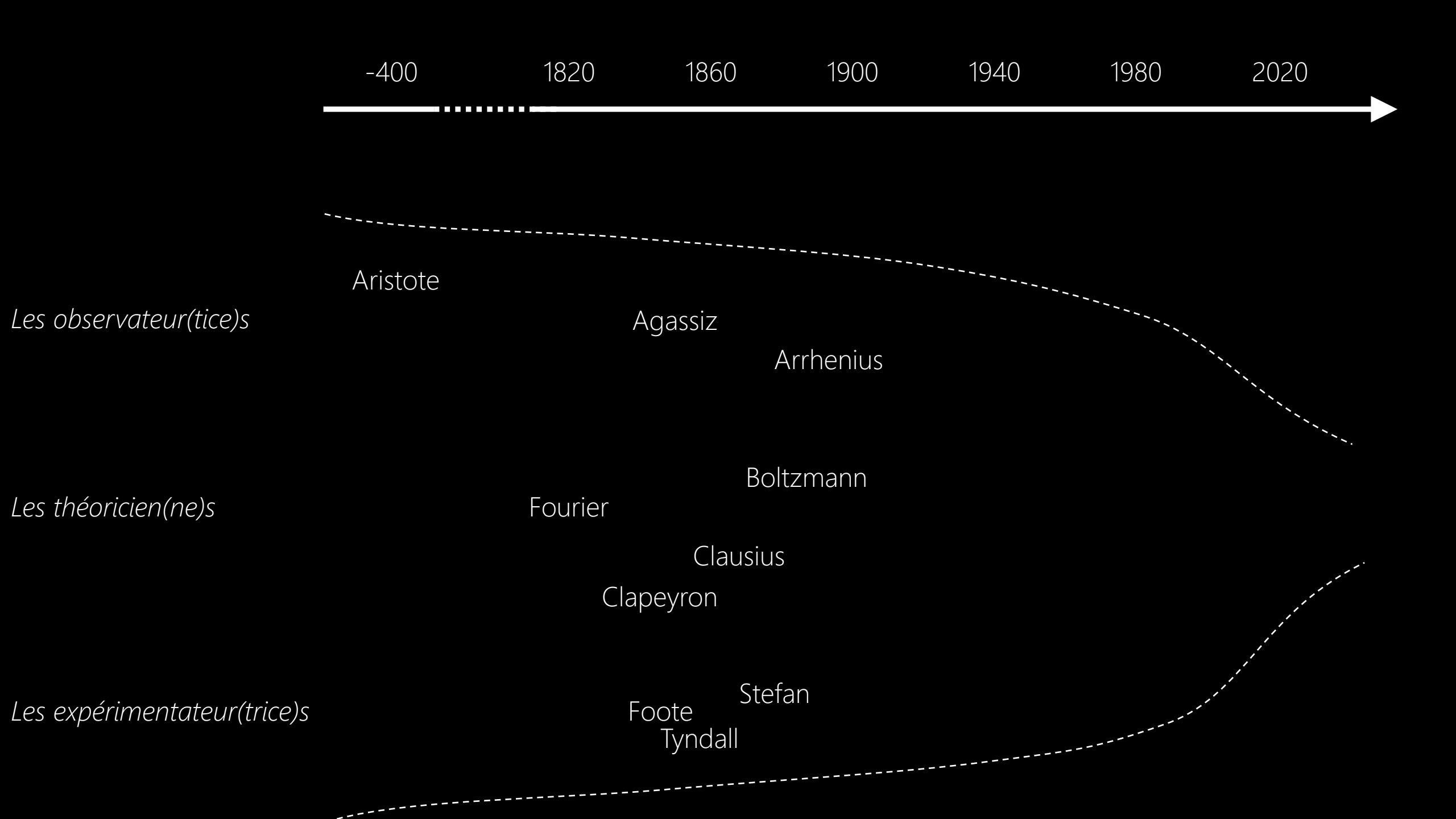
Amplification de la réponse aux hautes latitudes

Sensibilité climatique 4-6°C

Un siècle plus tard:

$$\Delta F = 5.35 \ln \frac{C}{C_0}$$

Myhre, G., Highwood, E. J., Shine, K. P., & Stordal, F. (1998). New estimates of radiative forcing due to well mixed greenhouse gases. Geophysical Research Letters, 25(14), 2715–2718. https://doi.org/10.1029/98GL01908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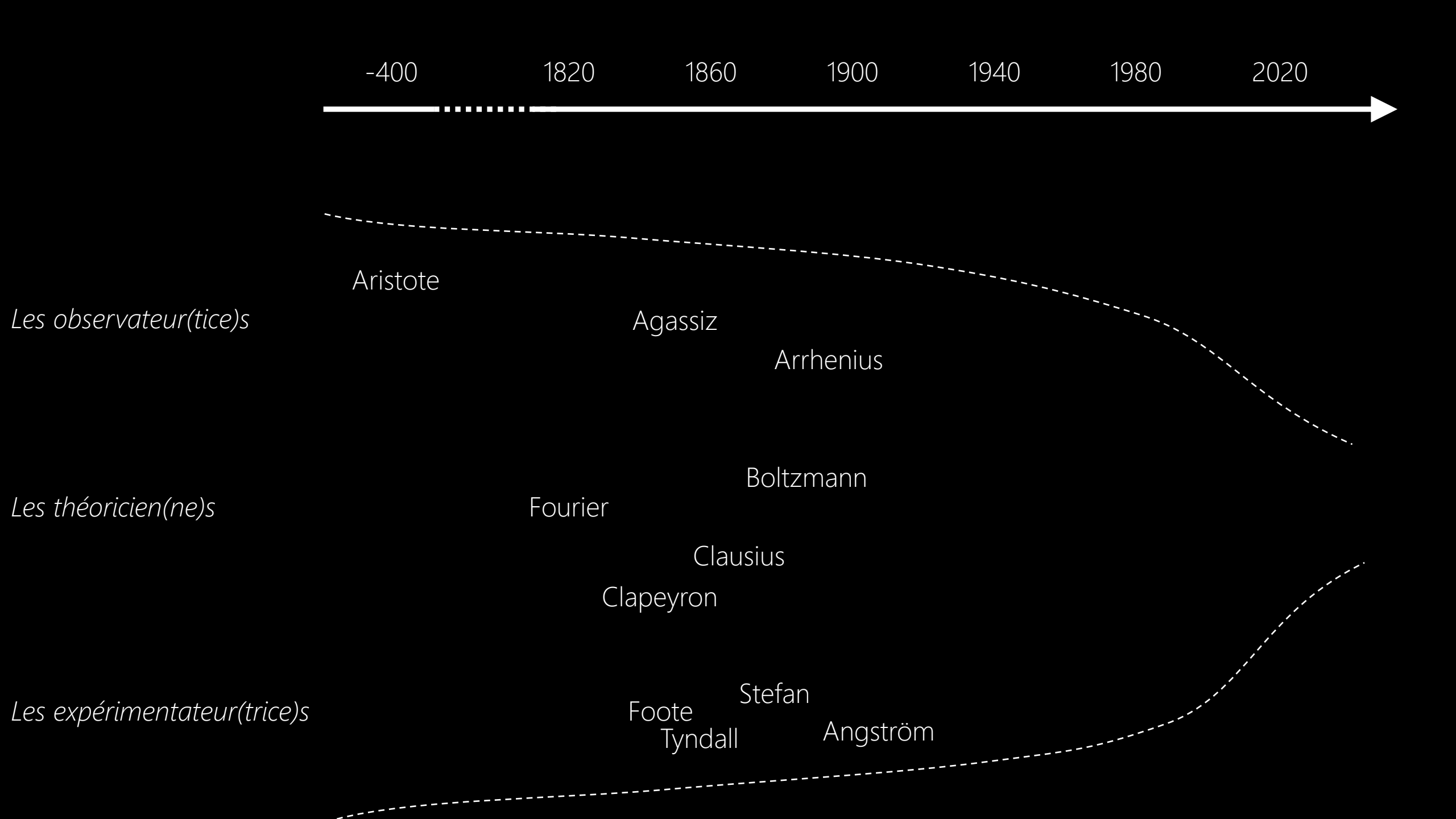
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Knut Ångström (1859-1927)

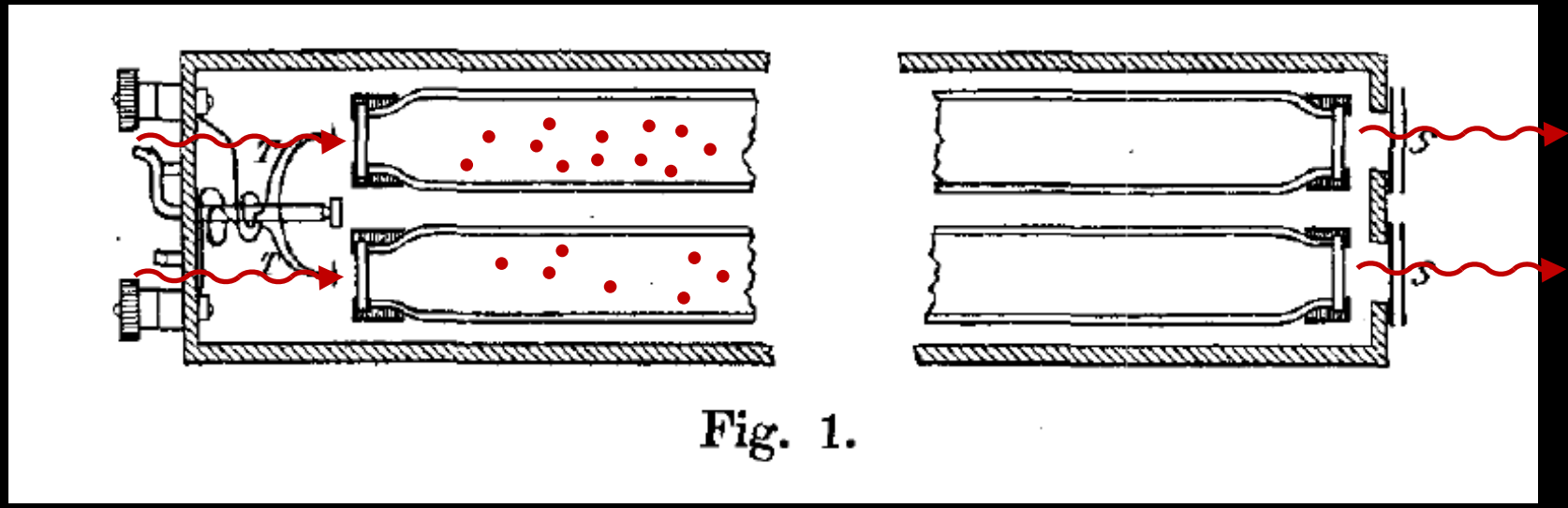
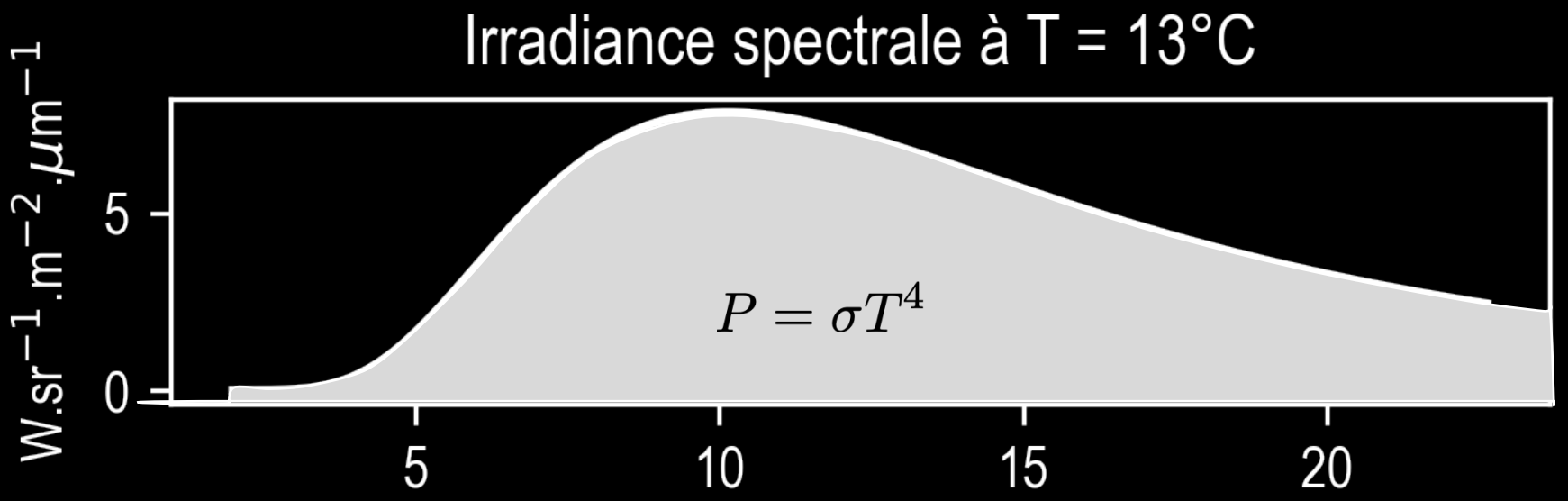


Fig. 1.

1900

Ångström, K. (1900). Ueber die Bedeutung des Wasserdampfes und der Kohlensäure bei der Absorption der Erdatmosphäre. Annalen der Physik, 308(12), 720–732. https://doi.org/10.1002/andp.19003081208


Irradiance spectrale à T = 13°C
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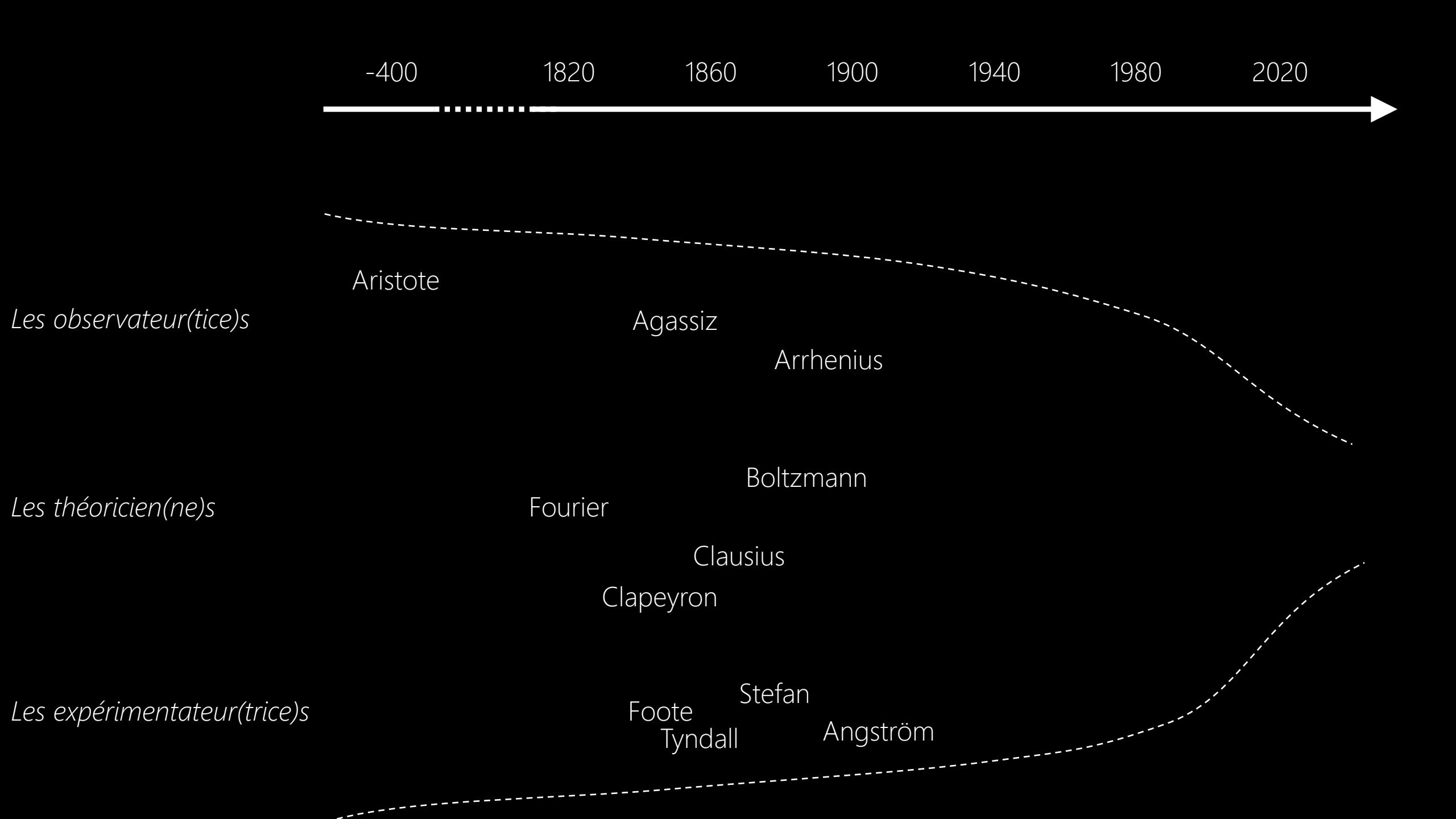
$P = \sigma T^4$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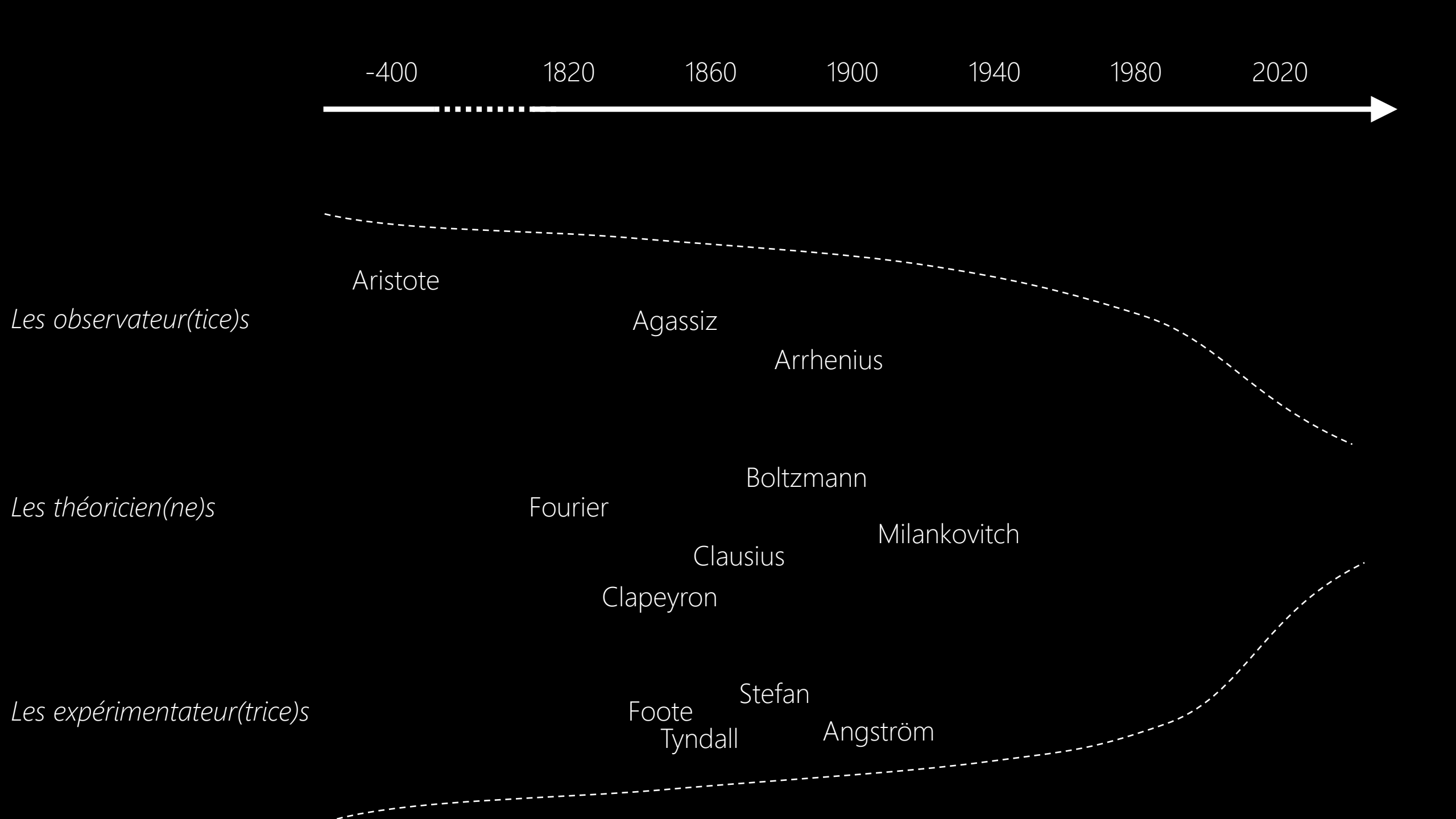
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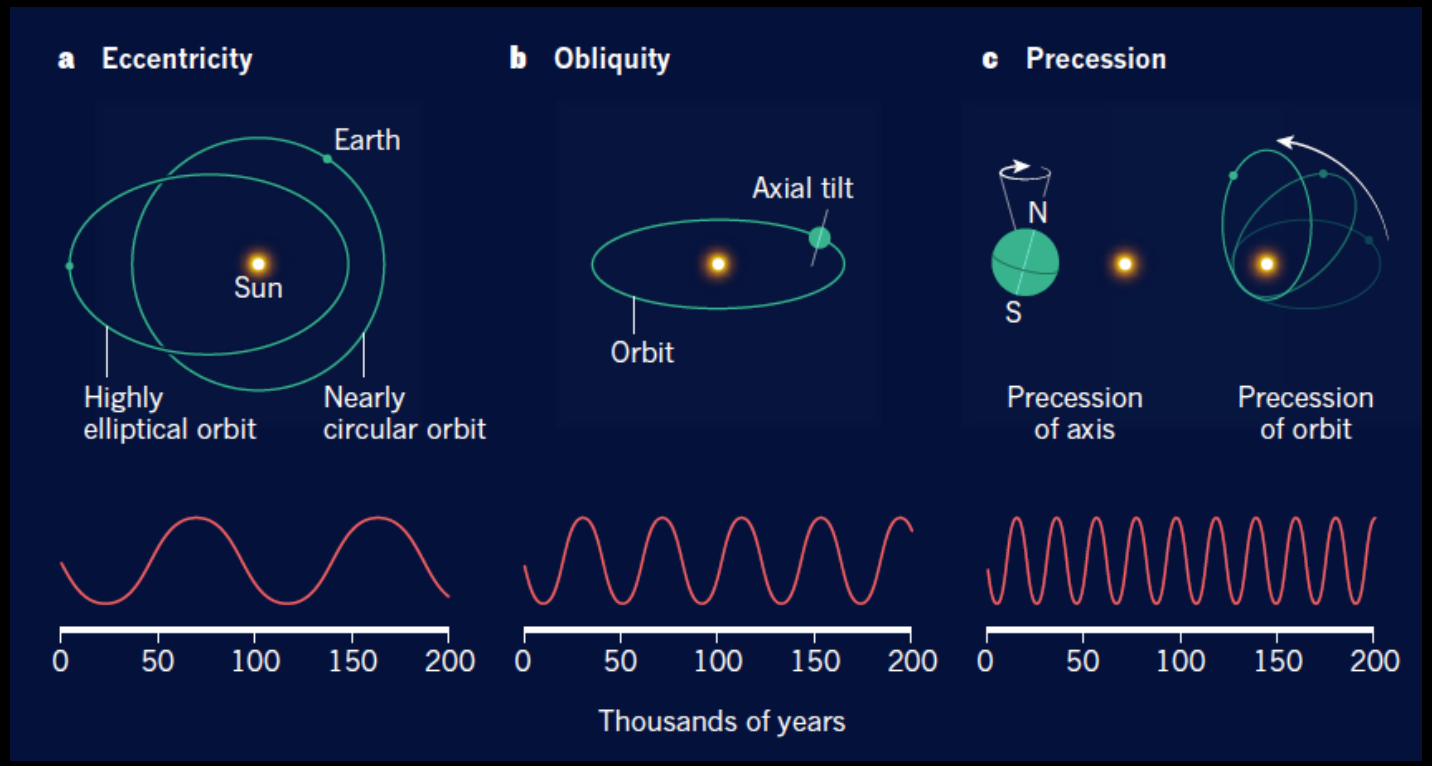
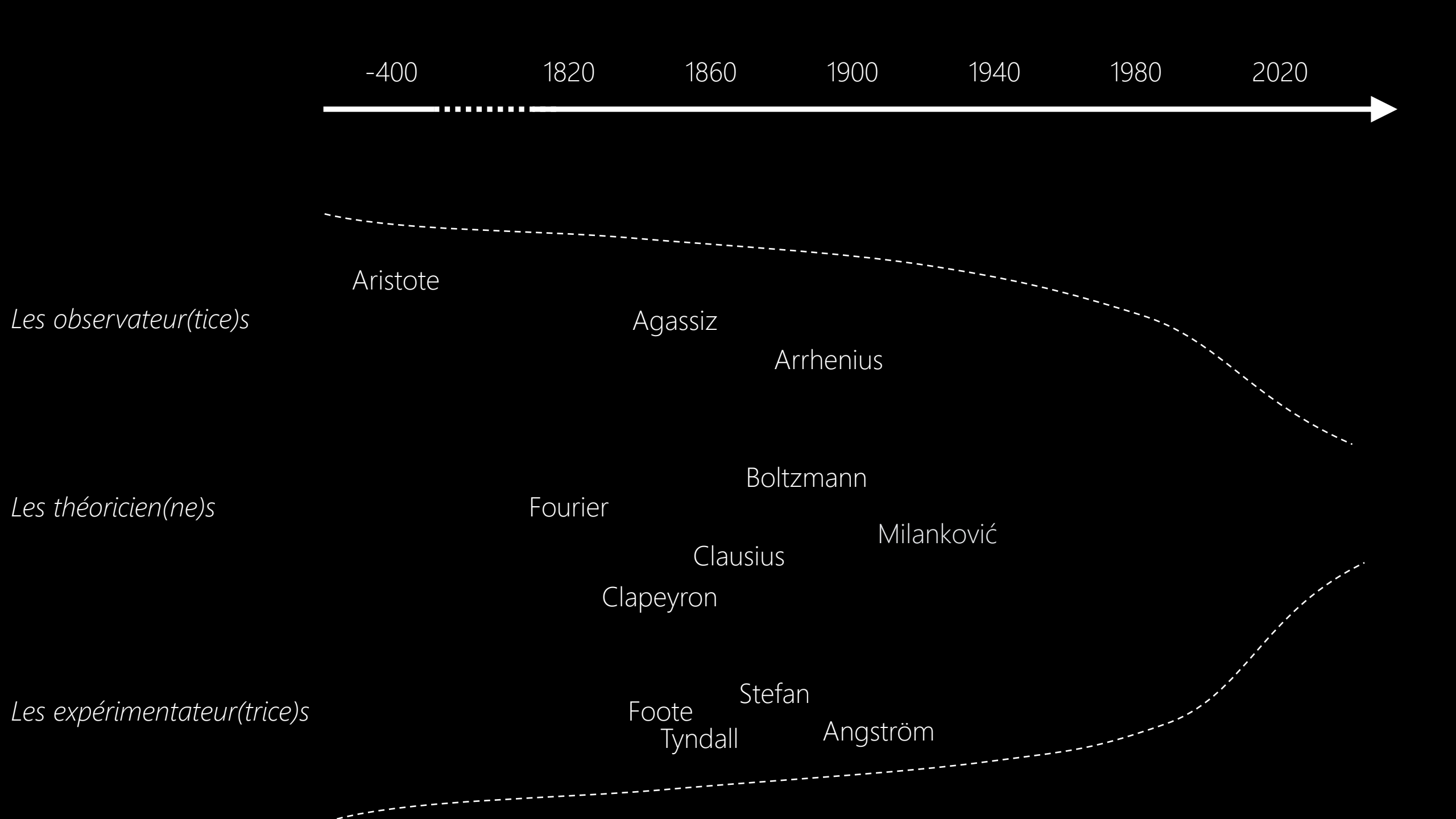
Milutin Milanković (1879-1958)



1920-1941

Maslin, M. (2016). Forty years of linking orbits to ice ages. Nature, 540(7632), Article 7632. https://doi.org/10.1038/540208a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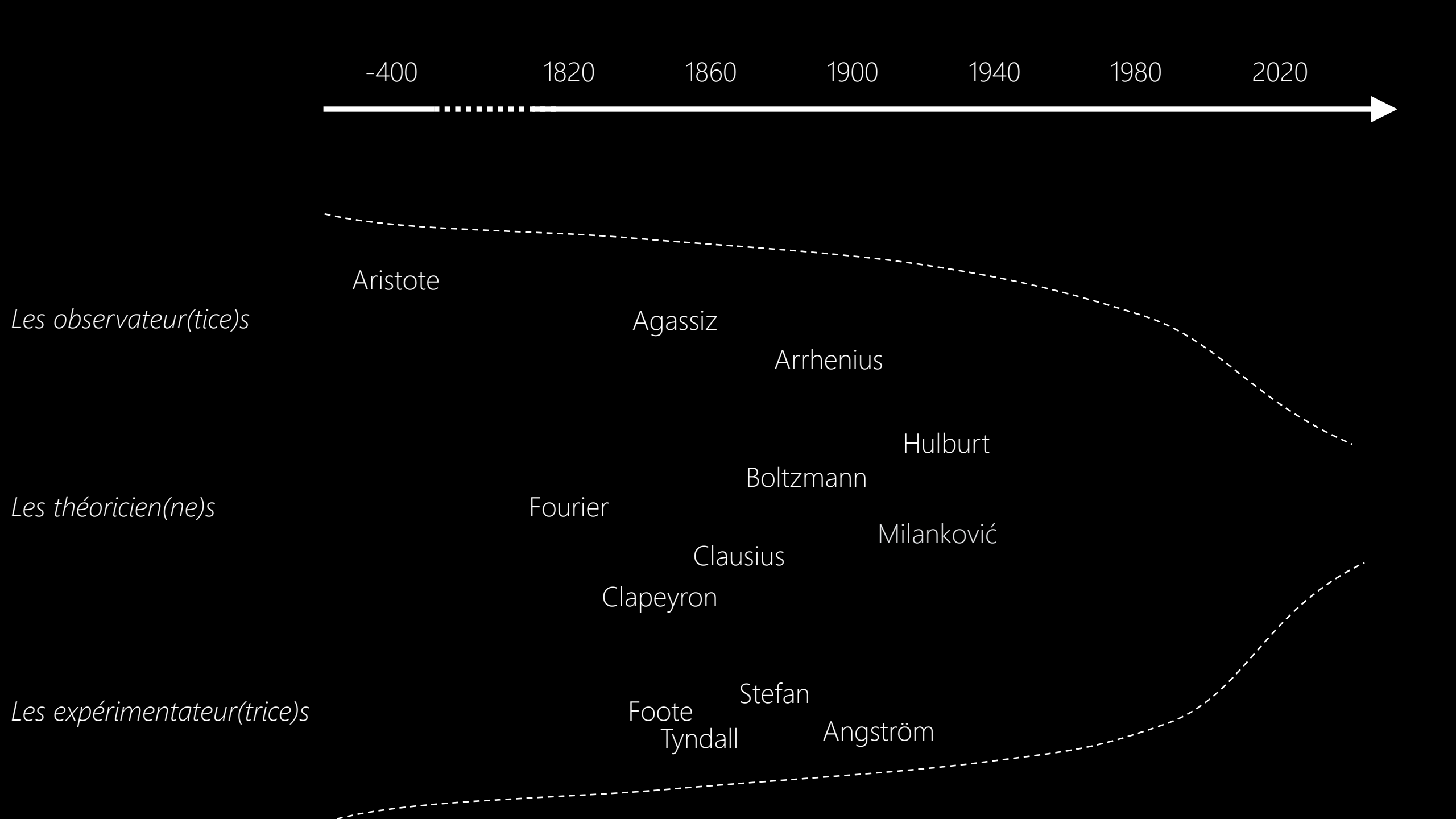
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Les observateur(tice)s
Les théoricien(ne)s
Les expérimentateur(trice)s

Edward Hulburt (1890-1982)

NOVEMBER 15, 1931 *PHYSICAL REVIEW* *VOLUME 38*

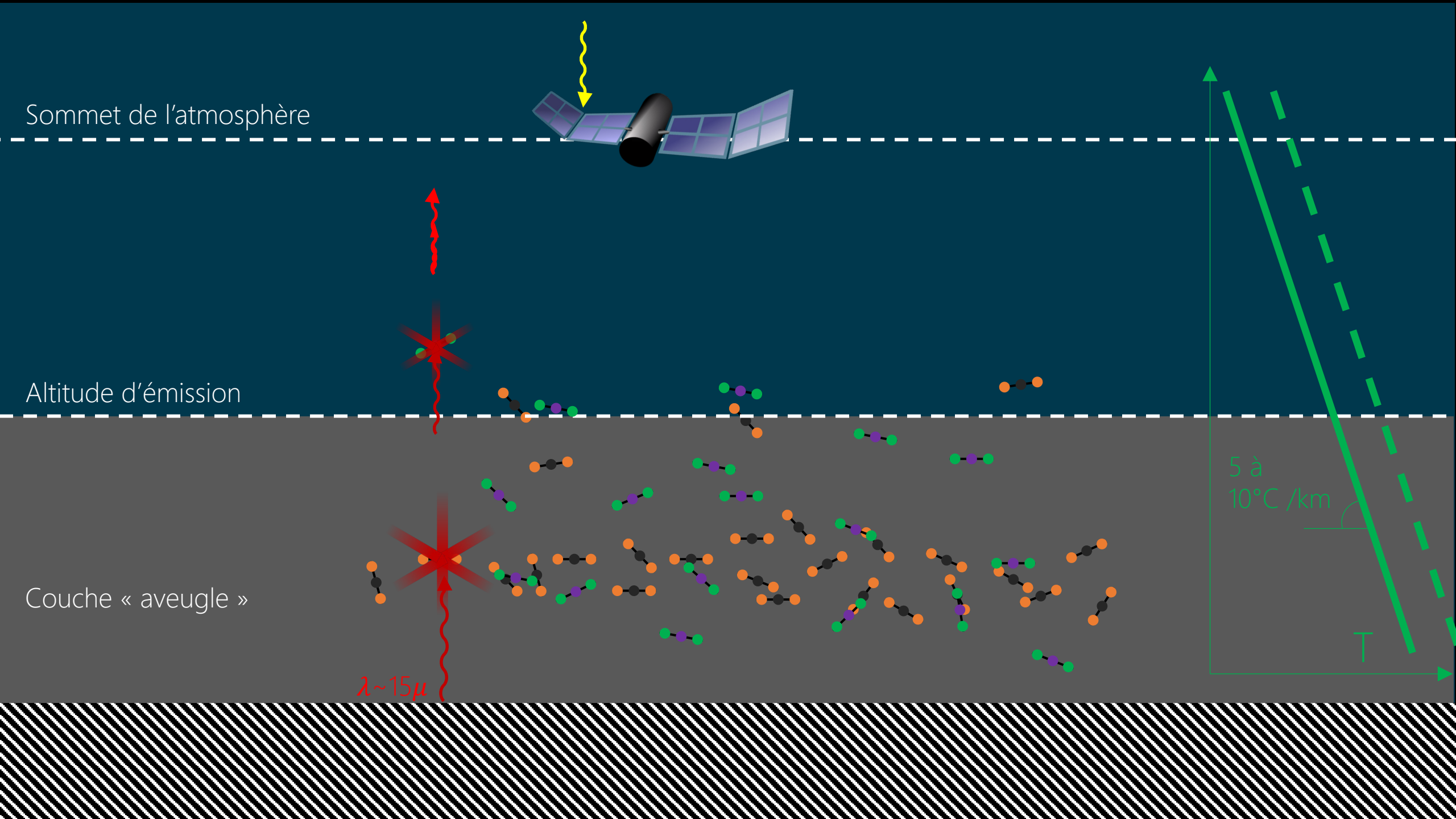
THE TEMPERATURE OF THE LOWER ATMOSPHERE OF THE EARTH*

By E. O. Hulburt
Naval Research Laboratory

(Received October 9, 1931)

1931

Hulburt, E. O. (1931). The Temperature of the Lower Atmosphere of the Earth. Physical Review, 38(10), 1876–1890. https://doi.org/10.1103/PhysRev.38.1876


Sommet de l'atmosphère
Altitude d'émission
Couche « aveugle »
λ~15μ
5 à
10°C /km
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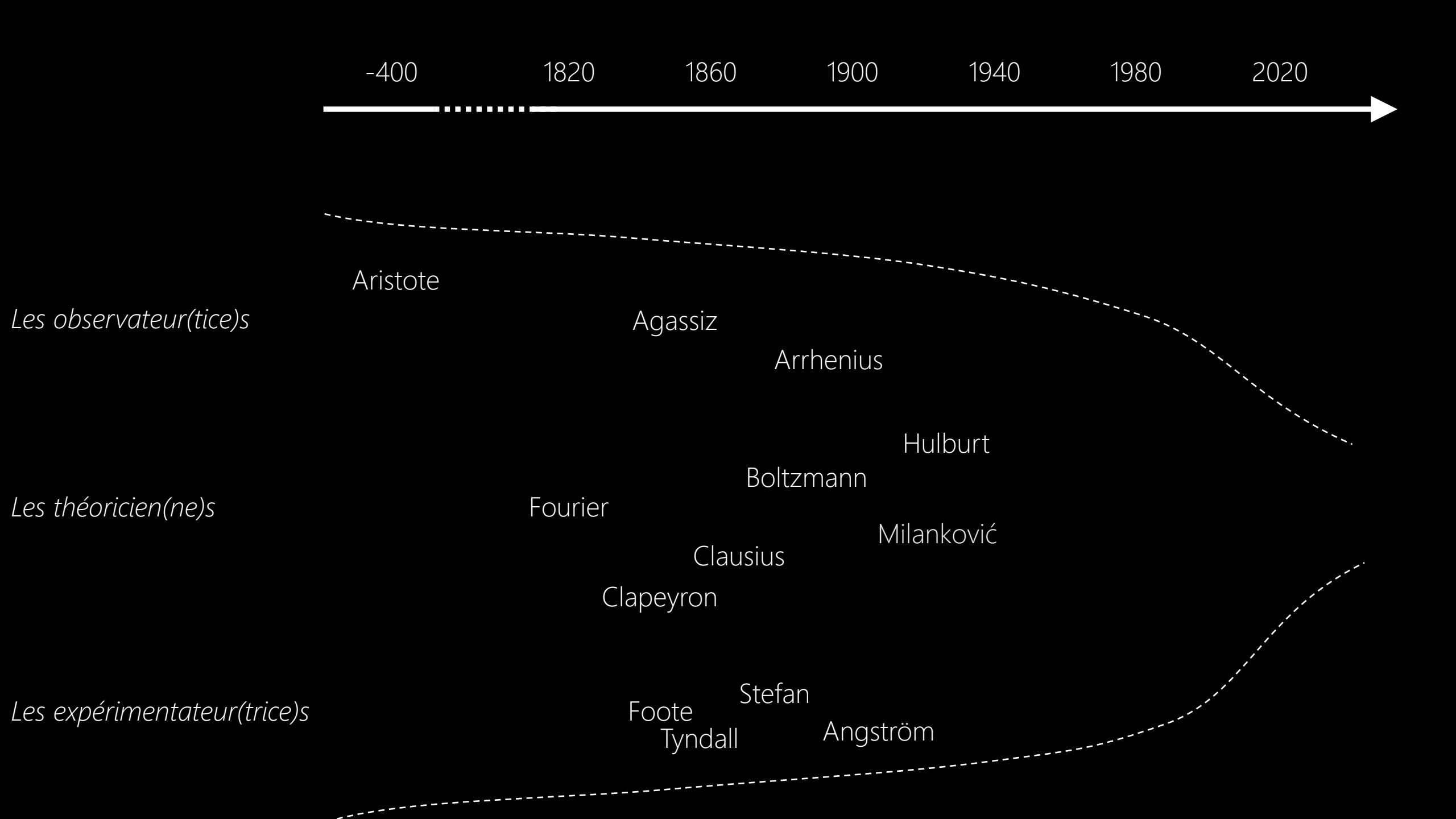
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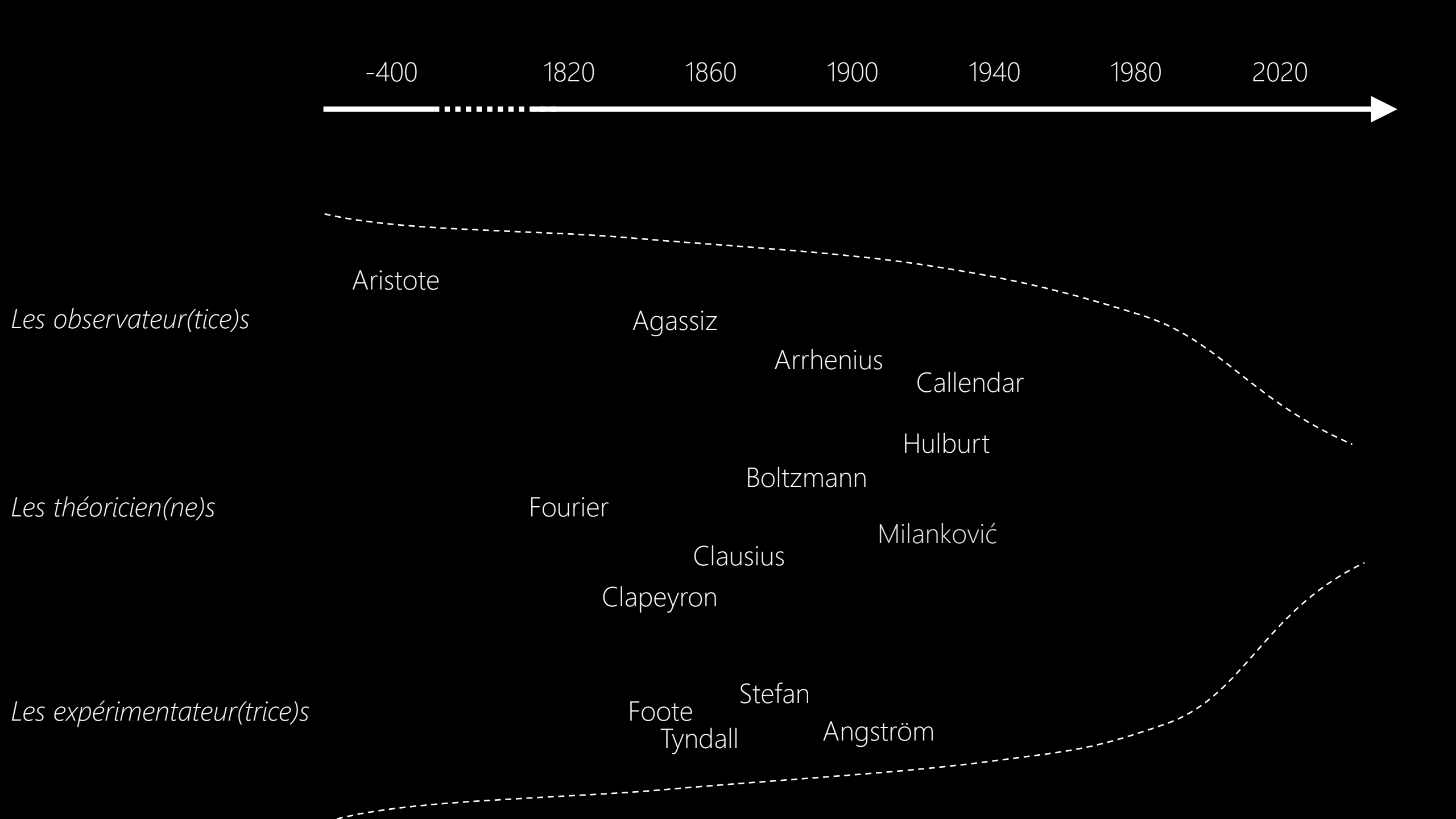
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Les expérimentateur(trice)s
Foote
Tyndall
Angström

Guy Callendar (1898-1964)

THE ARTIFICIAL PRODUCTION OF CARBON DIOXIDE AND ITS INFLUENCE ON TEMPERATURE

By G. S. CALLENDAR

(Steam technologist to the British Electrical and Allied Industries Research Association.)

(Communicated by Dr. G. M. B. Dobson, F.R.S.)

[Manuscript received May 19, 1937—read February 16, 1938.]

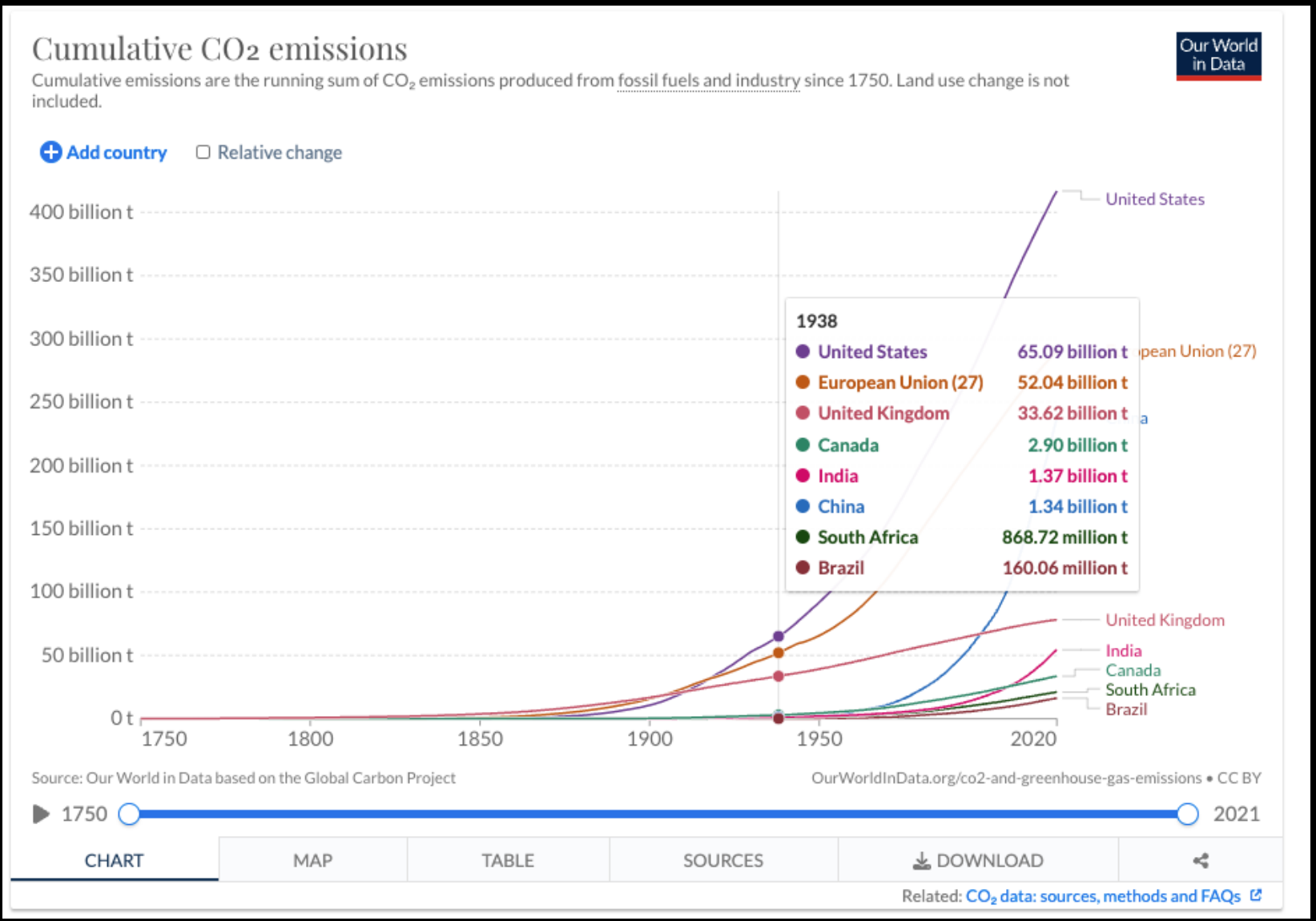
SUMMARY

By fuel combustion man has added about 150,000 million tons of carbon dioxide to the air during the past half century. The author estimates from the best available data that approximately three quarters of this has remained in the atmosphere.

The radiation absorption coefficients of carbon dioxide and water vapour are used to show the effect of carbon dioxide on "sky radiation." From this the increase in mean temperature, due to the artificial production of carbon dioxide, is estimated to be at the rate of 0·003°C. per year at the present time.

The temperature observations at 200 meteorological stations are used to show that world temperatures have actually increased at an average rate of 0·005°C. per year during the past half century.

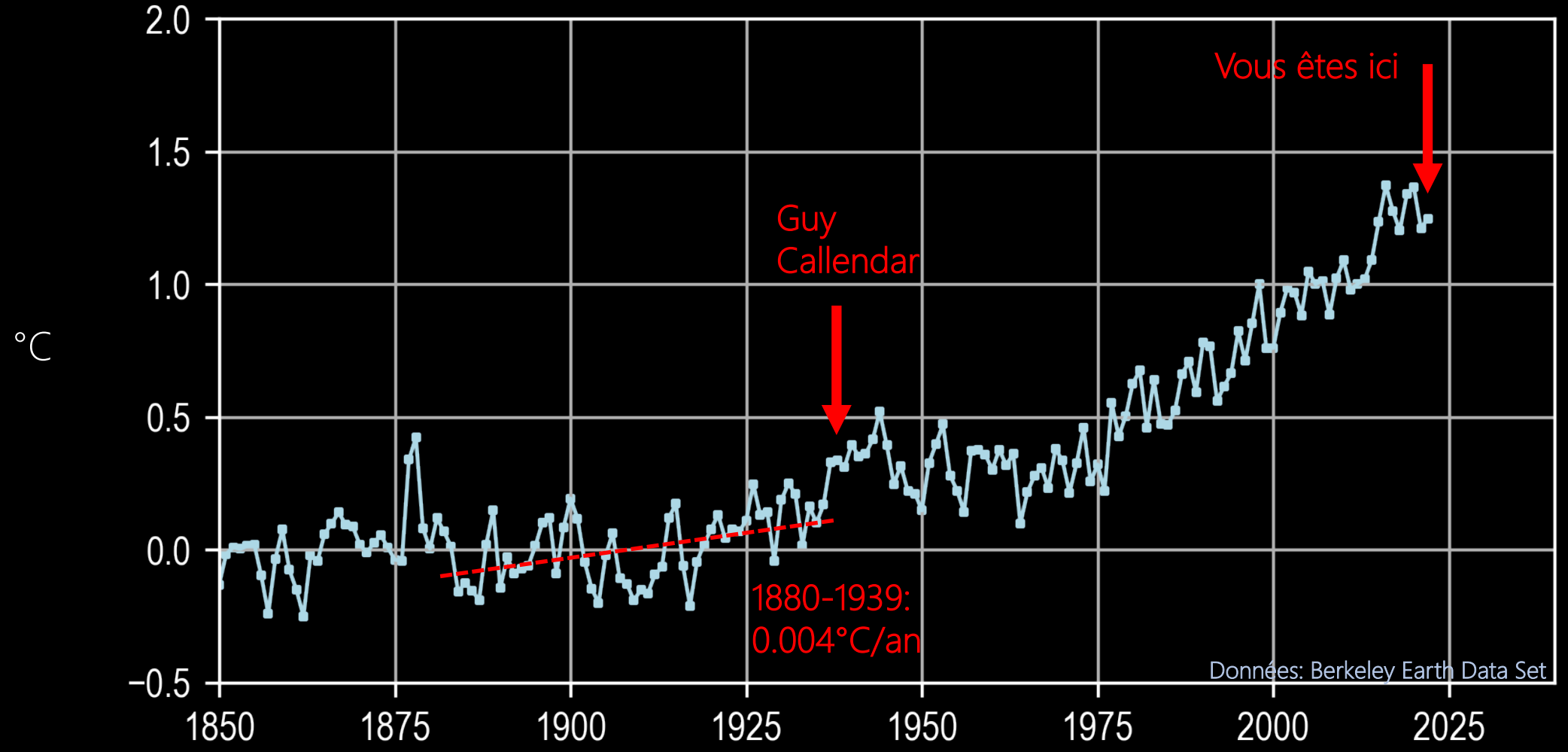
1938



$\sum$ = 157 Gt CO_2

(1750→1938)

Evolution des anomalies de la température de l'air en moyenne annuelle et globale par rapport à la moyenne 1850-1899



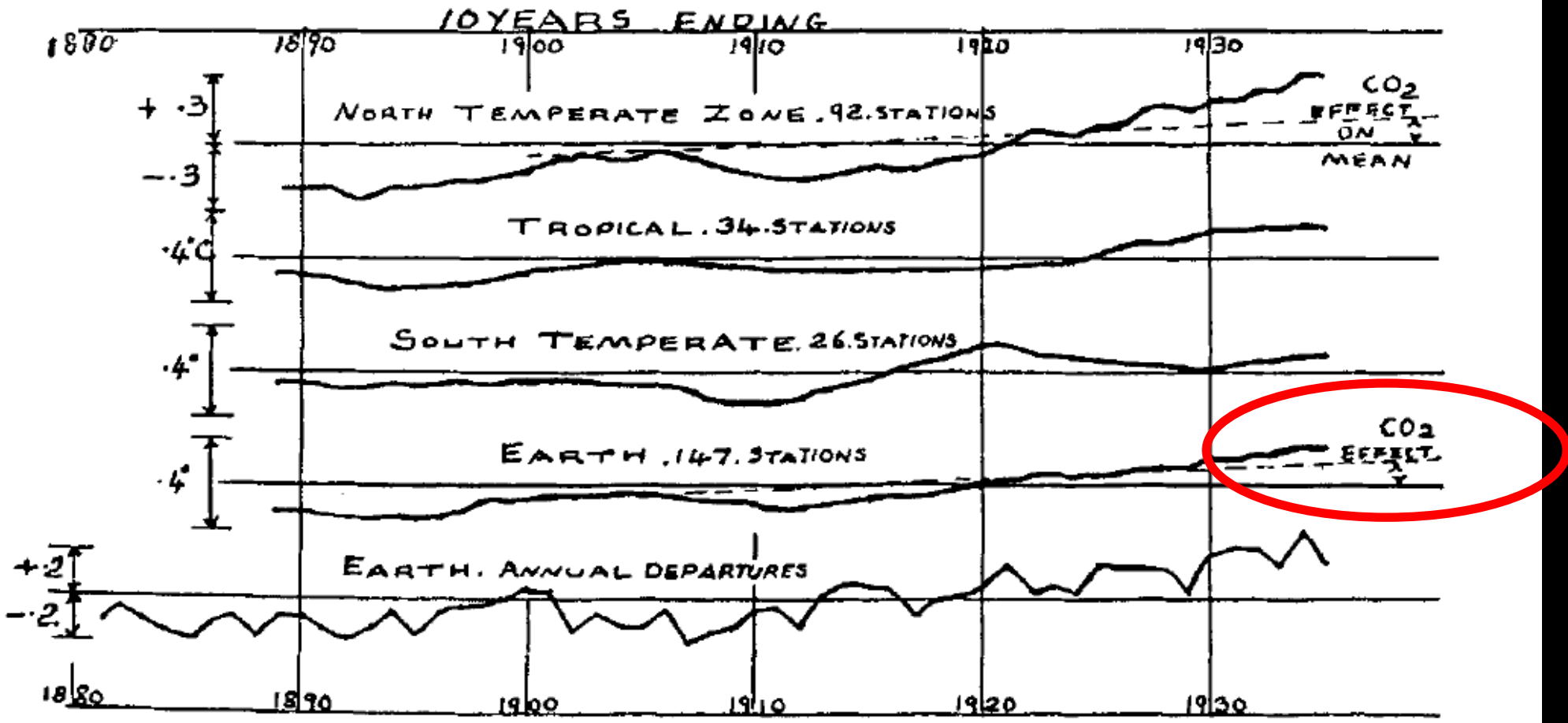
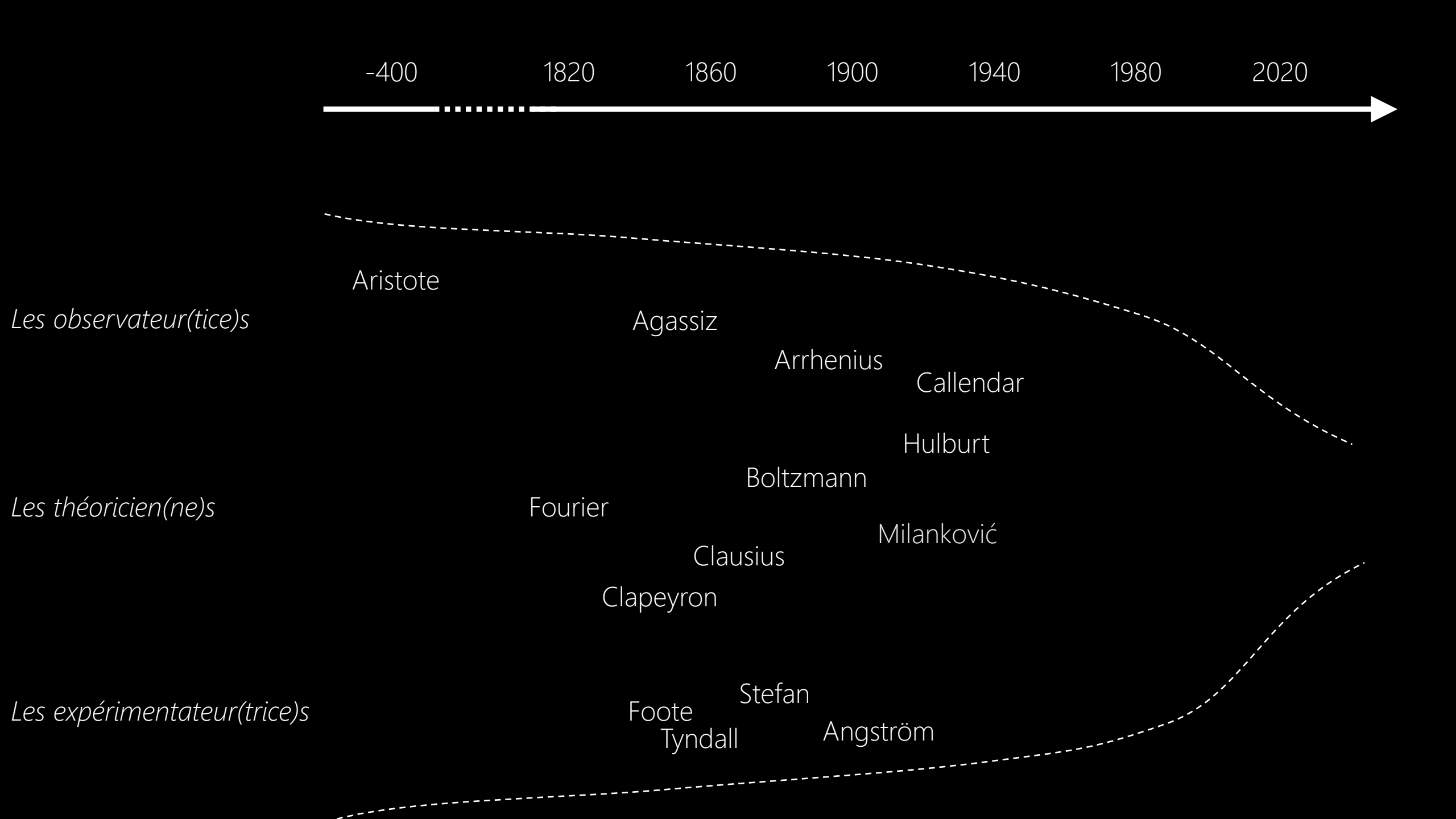


FIG. 4.—Temperature variations of the zones and of the earth. Ten-year moving departures from the mean, 1901-1930. °C.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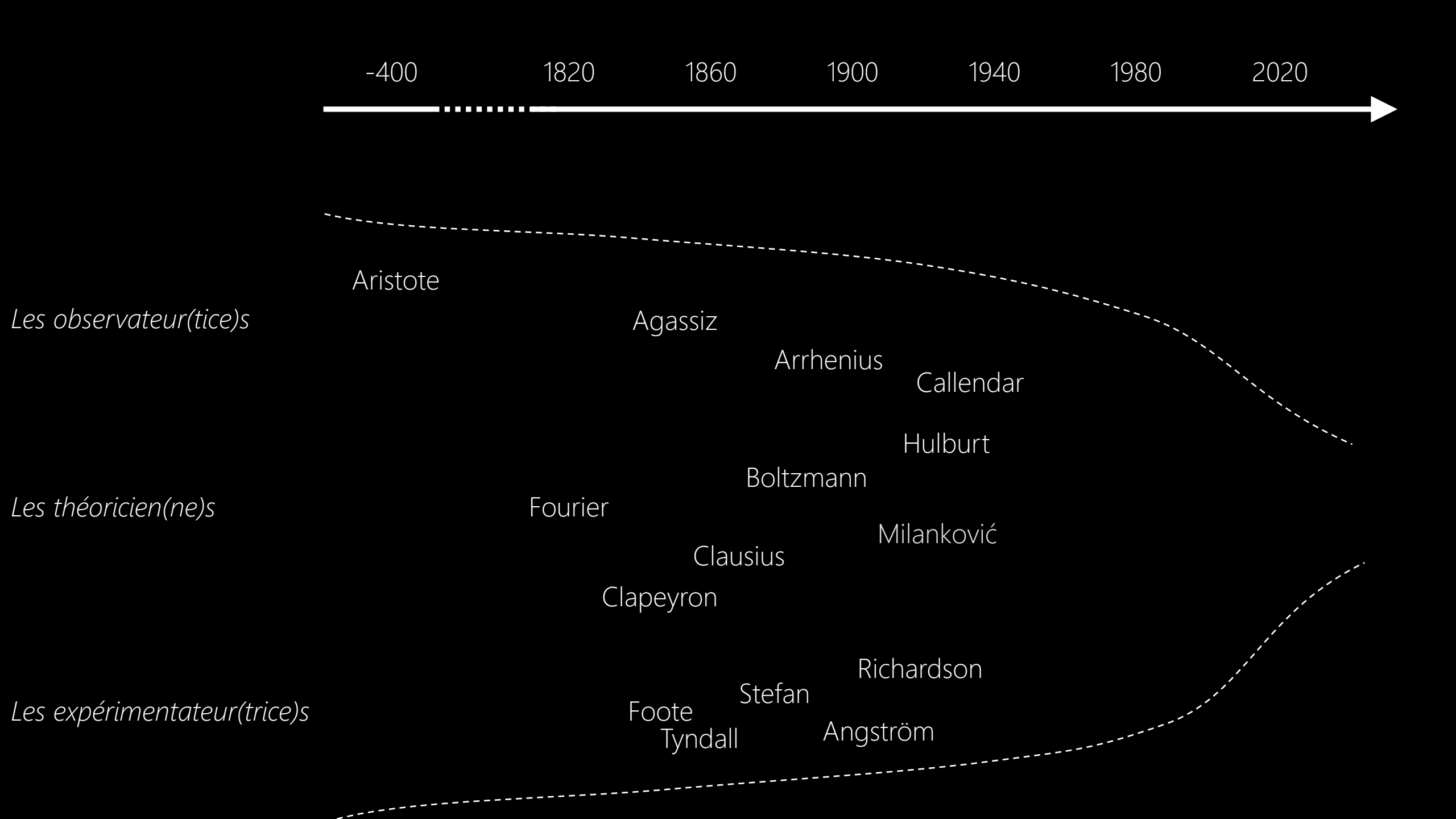
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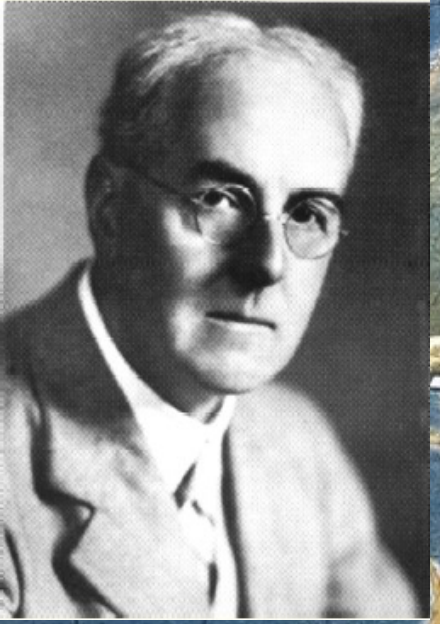
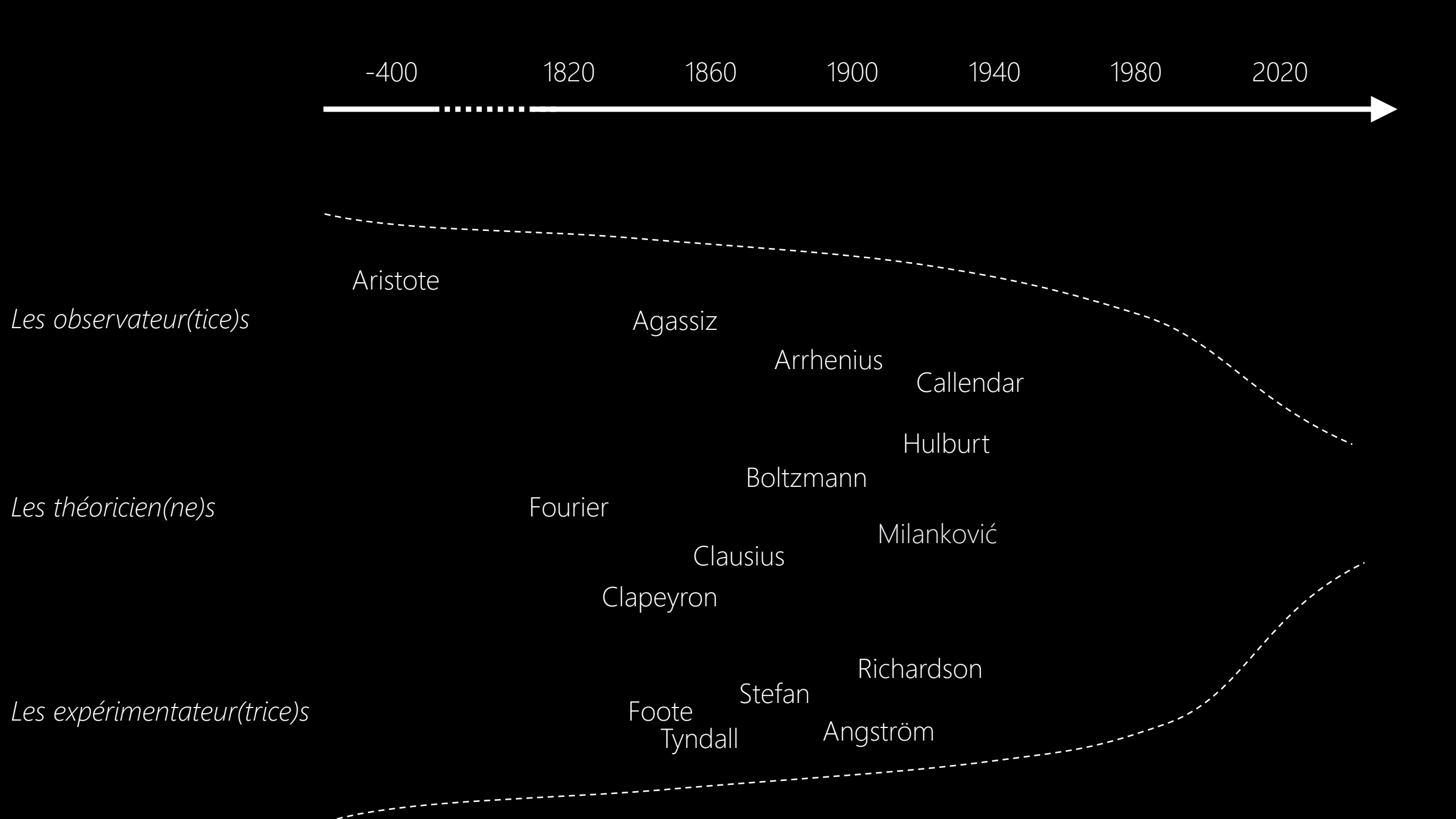


Lewis Fry Richardson (1881-1953)

1922

Mendez, M. (2015). Scientific Software: Legacy Software Maintenance. https://doi.org/10.13140/RG.2.2.12463.84648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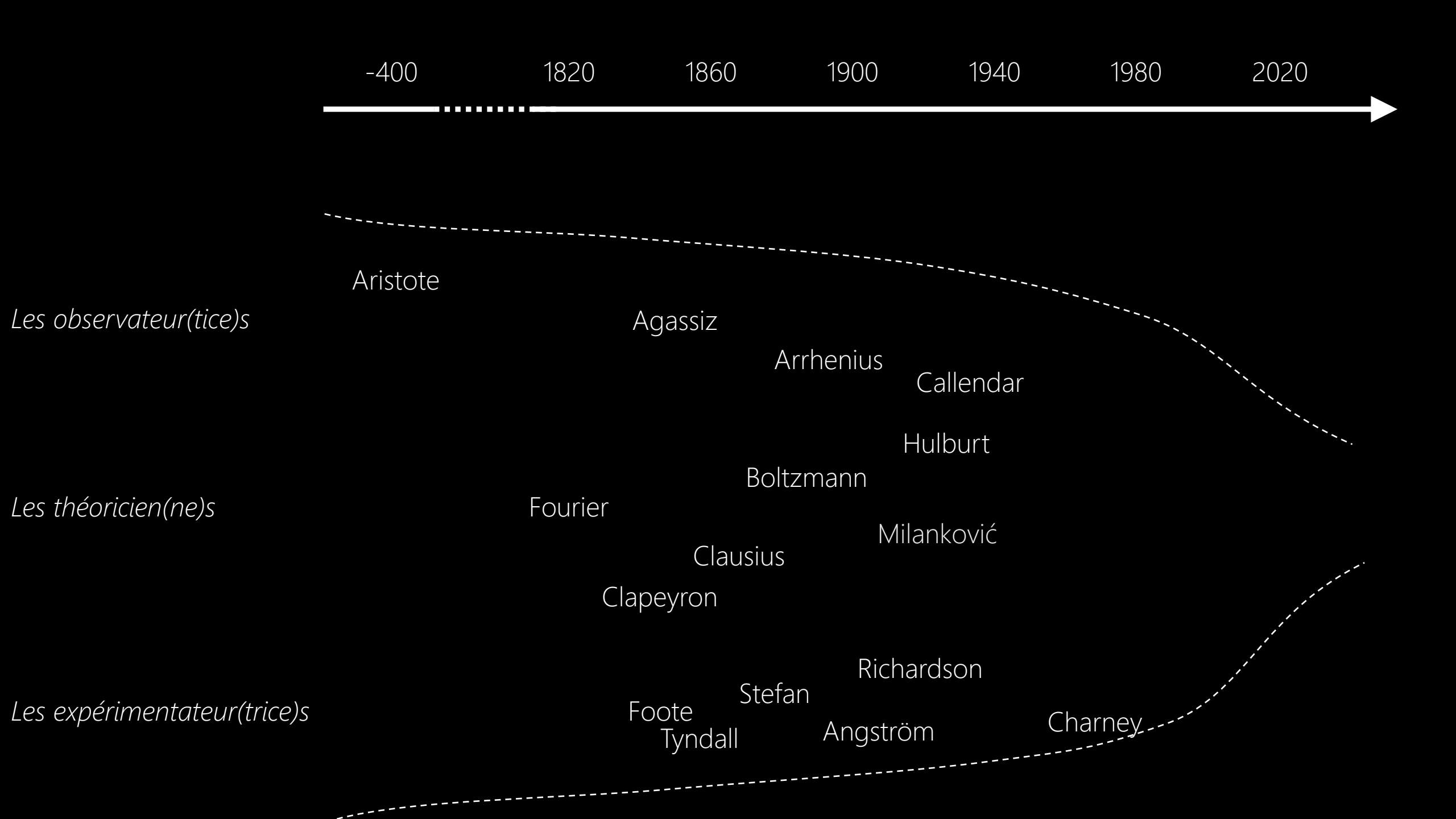
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Angström
Charney
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Les expérimentateur(trice)s

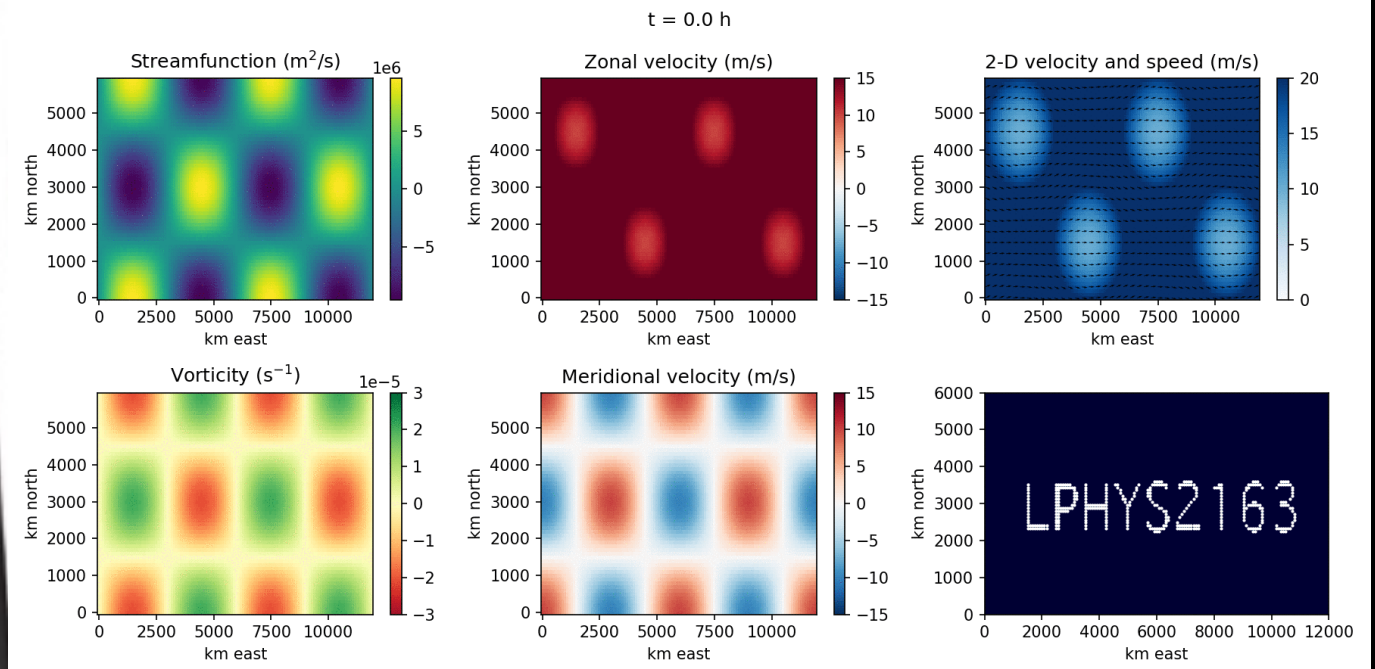
Jules Gregory Charney (1917-1981)

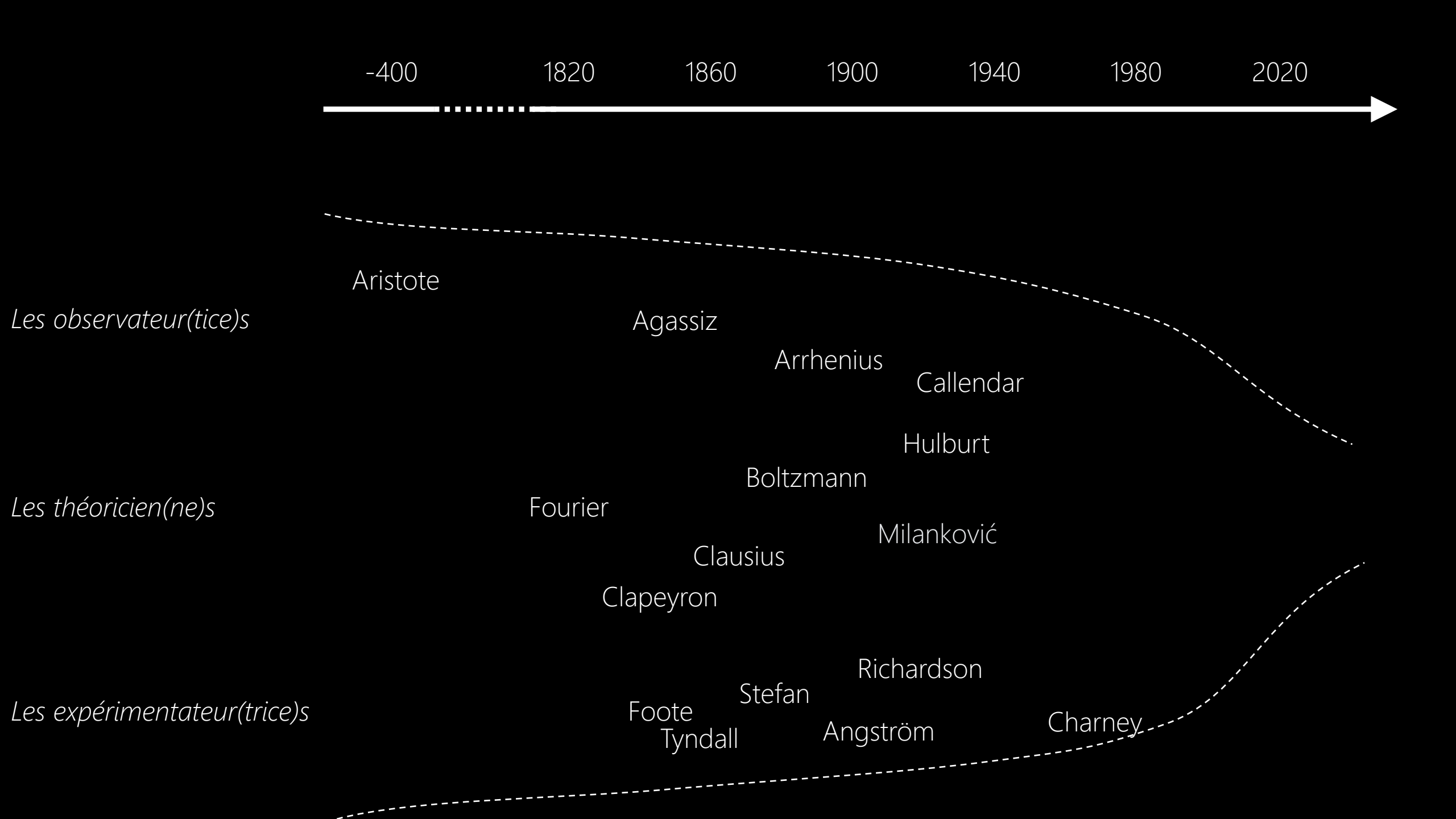
A QUARTERLY JOURNAL OF GEOPHYSICS

Numerical Integration of the Barotropic Vorticity Equation

By J. G. CHARNEY, R. FJÖRTOFT[1], J. von NEUMANN
The Institute for Advanced Study, Princeton, New Jersey[2]

(Manuscript received 1 November 1950)

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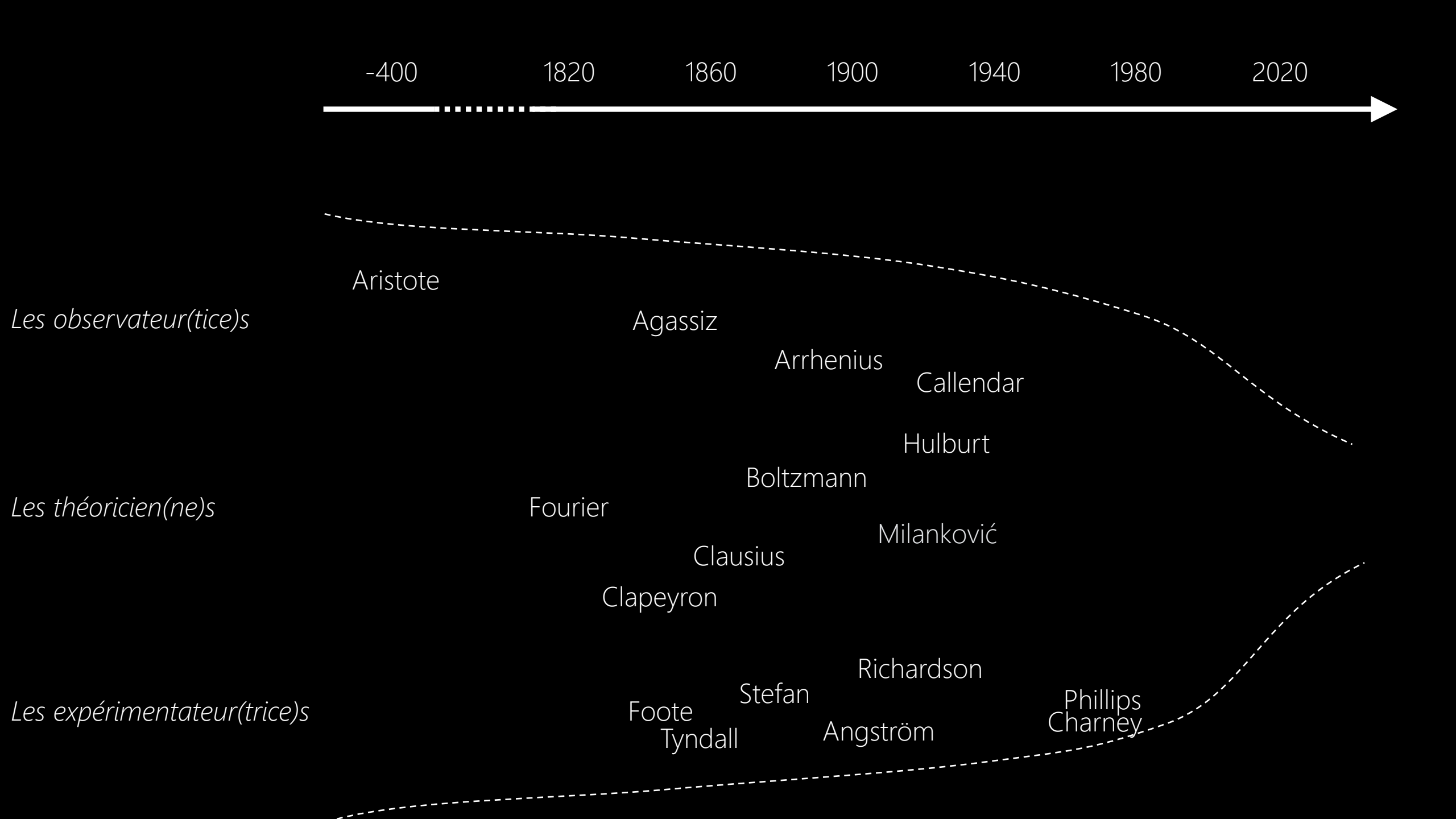
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Phillips
Charney
Tyndall
Angström

Norman Phillips (1923-2019)

QUARTERLY JOURNAL
OF THE
ROYAL METEOROLOGICAL SOCIETY

Vol. 82 APRIL 1956 No. 352

551.513.1 : 551.509.33 : 681.14

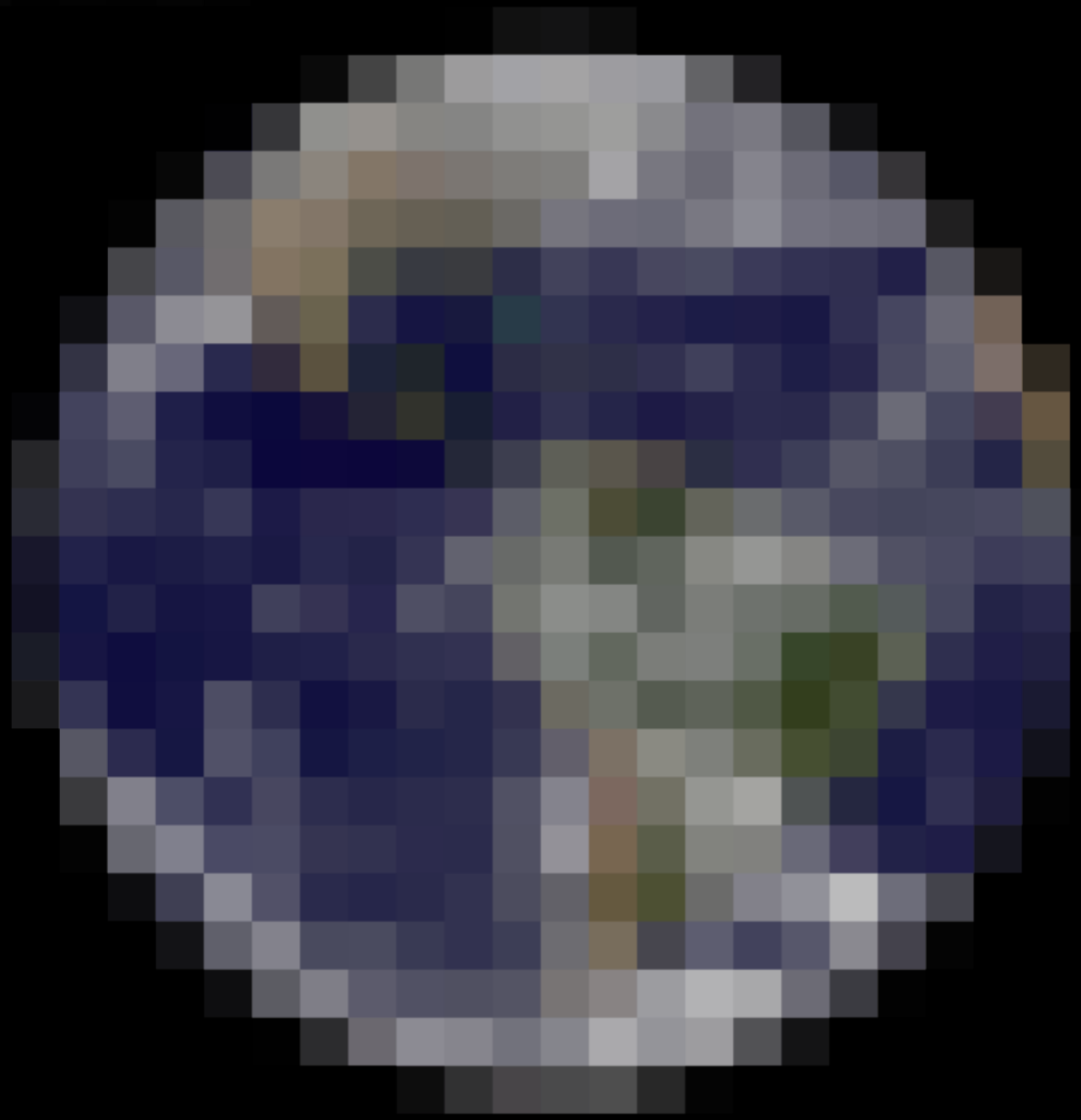
The general circulation of the atmosphere : a numerical experiment

By NORMAN A. PHILLIPS
The Institute for Advanced Study, Princeton, U.S.A.

(Manuscript received 17 October 1955)

« La taille de l'ordinateur électronique disponible pour les calculs détermine le nombre maximum de points de grille que nous pouvons utiliser pour décrire le mouvement dans notre région rectangulaire [...] ces considérations ont abouti au choix d'un réseau de points de grille de 17 x 16, 17 dans la direction des *y* et 16 dans la direction des *x*. »

1956



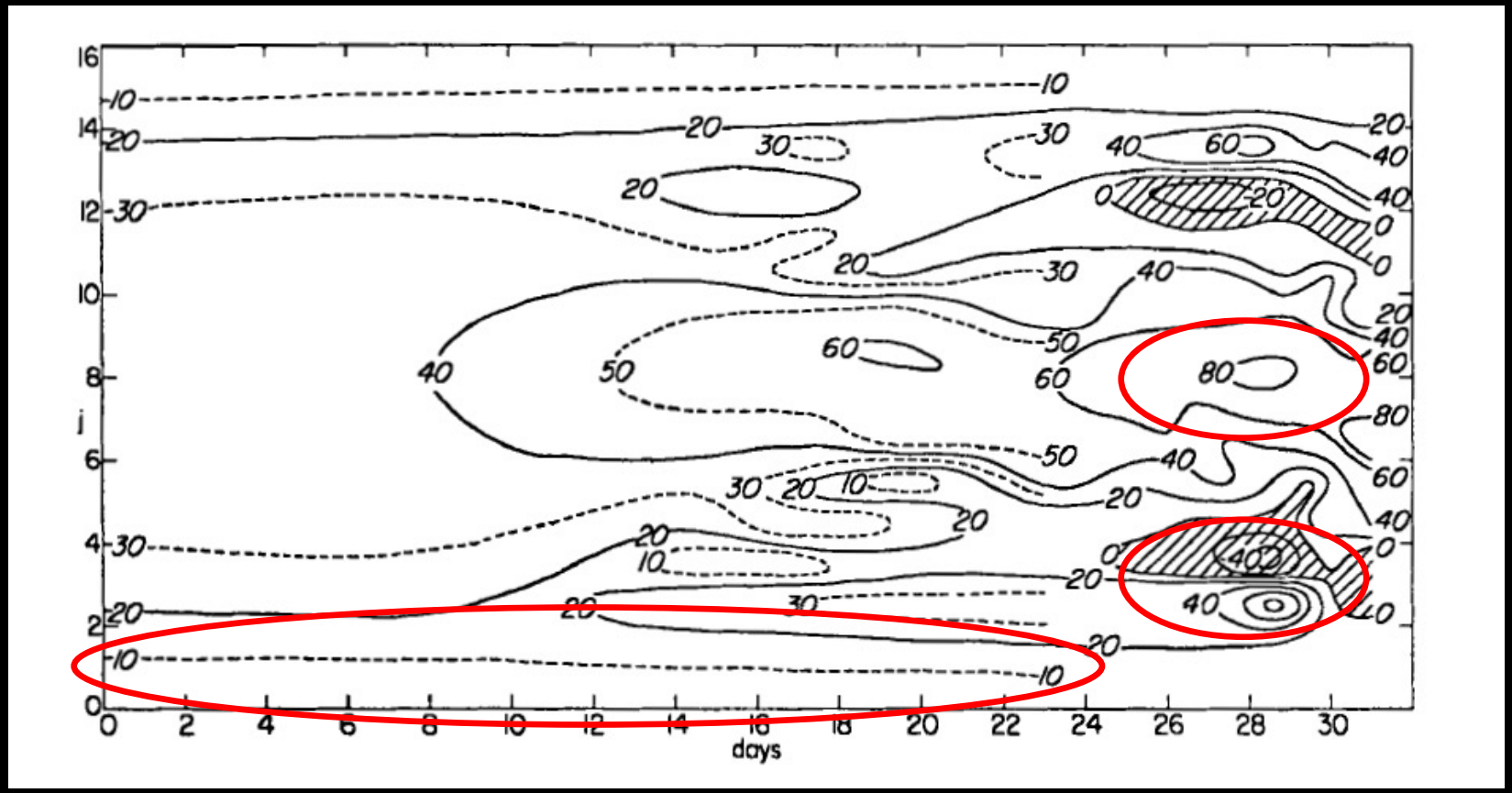
« La Terre vue par Phillips »

Vitesse du vent simulée à 250 hPa (~11 km)

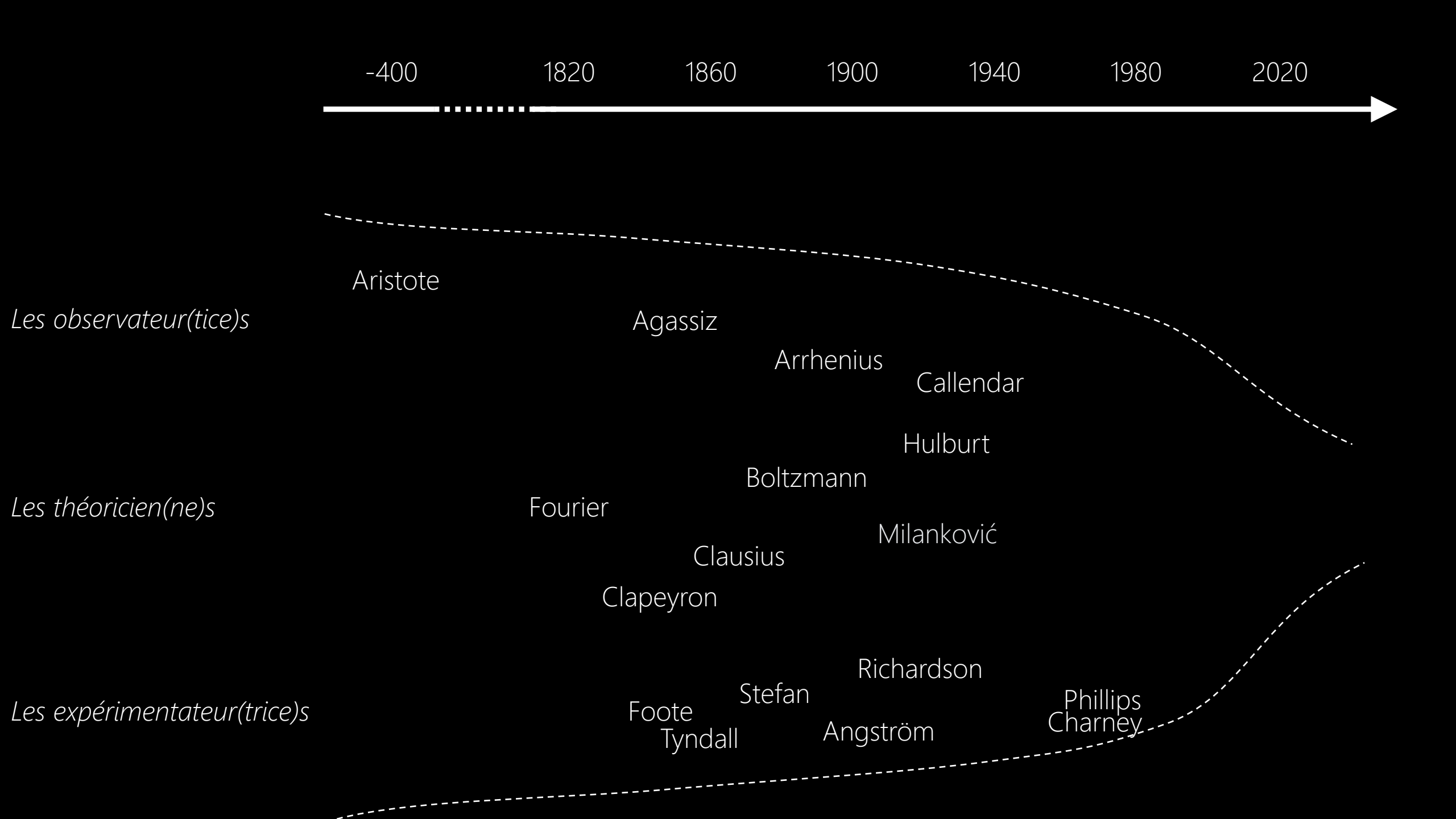
90 ° Pole

45°

0° Equateur



→ Temps d'intégration numérique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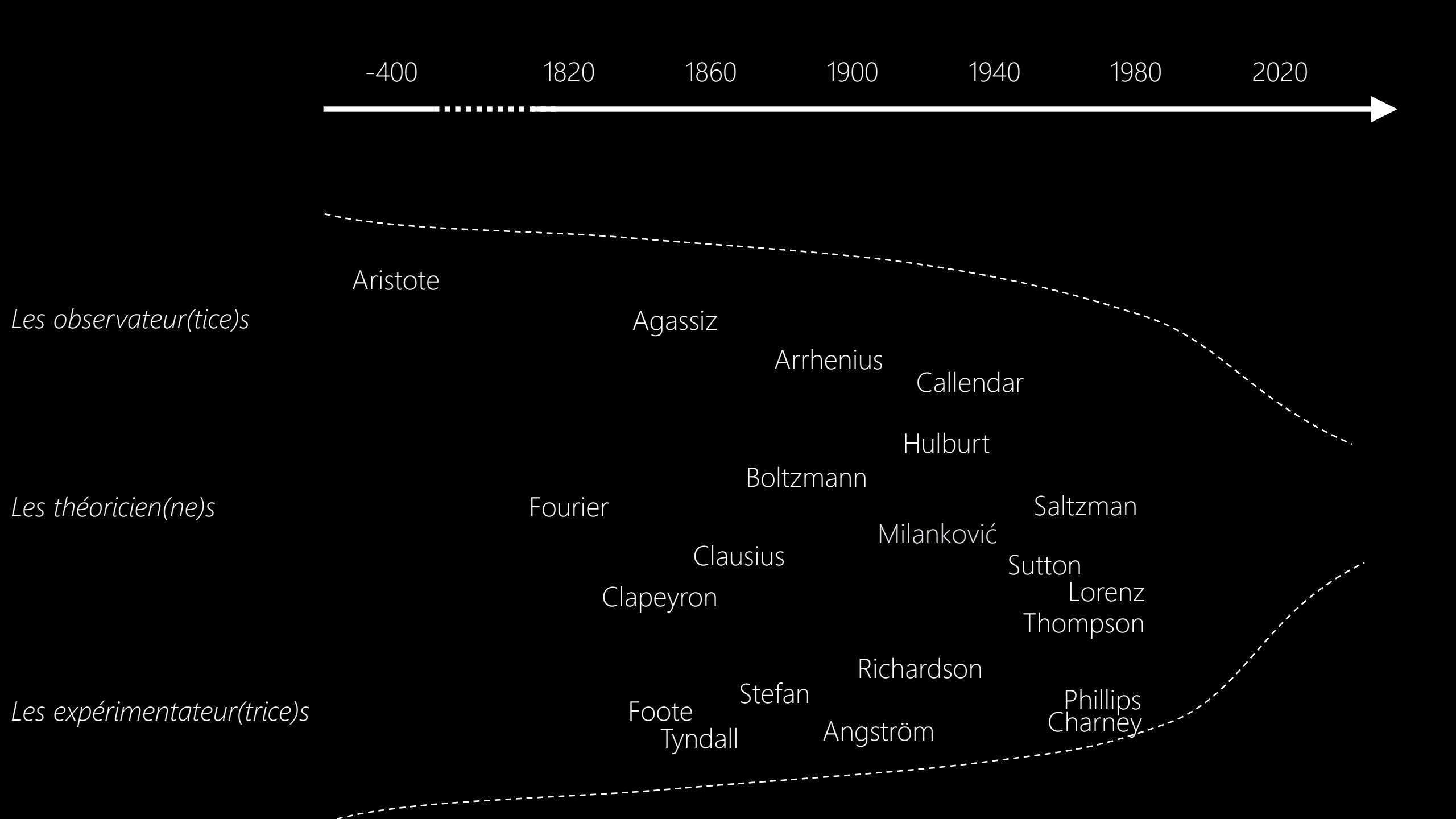
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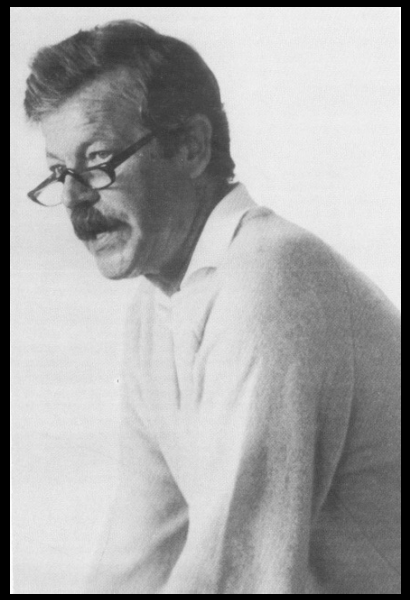
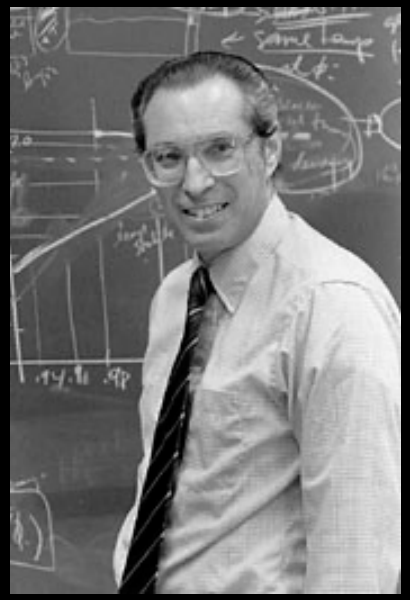
Angström

Oliver G. Sutton
(1903-1977)

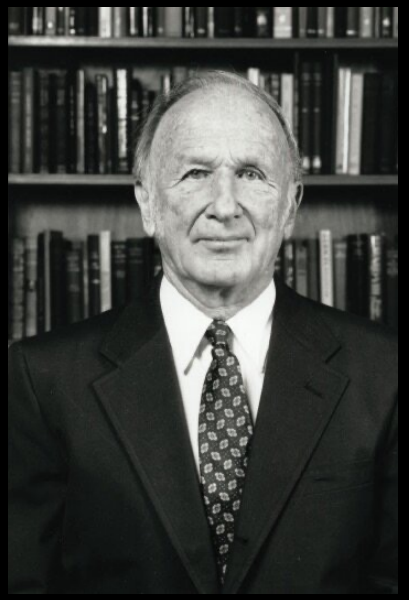
Philip D. Thompson
(1922-1994)

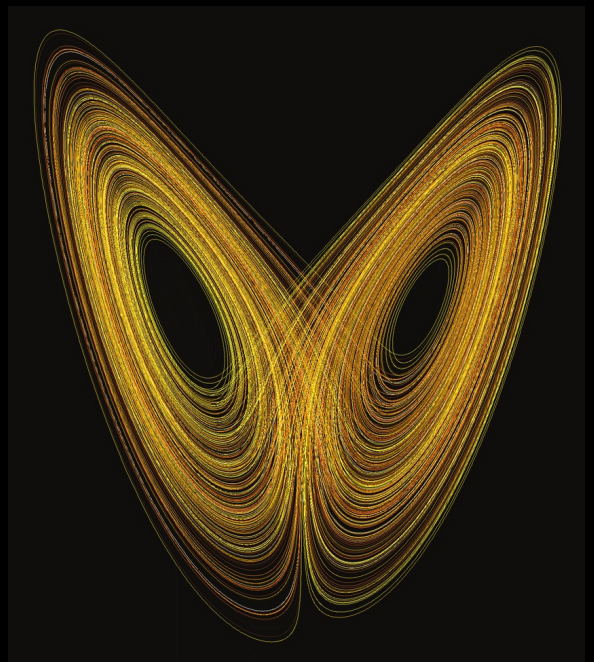


Barry Saltzman
(1931-2001)



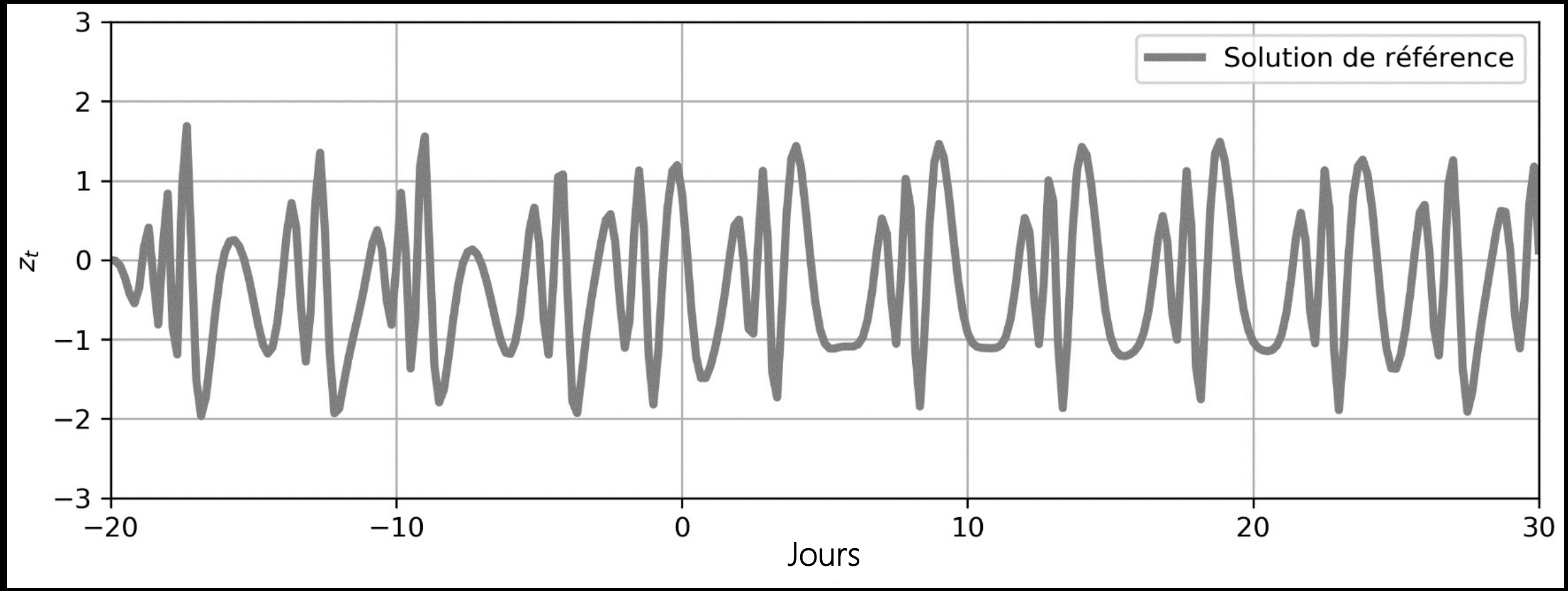
Edward N. Lorenz
(1917-2008)



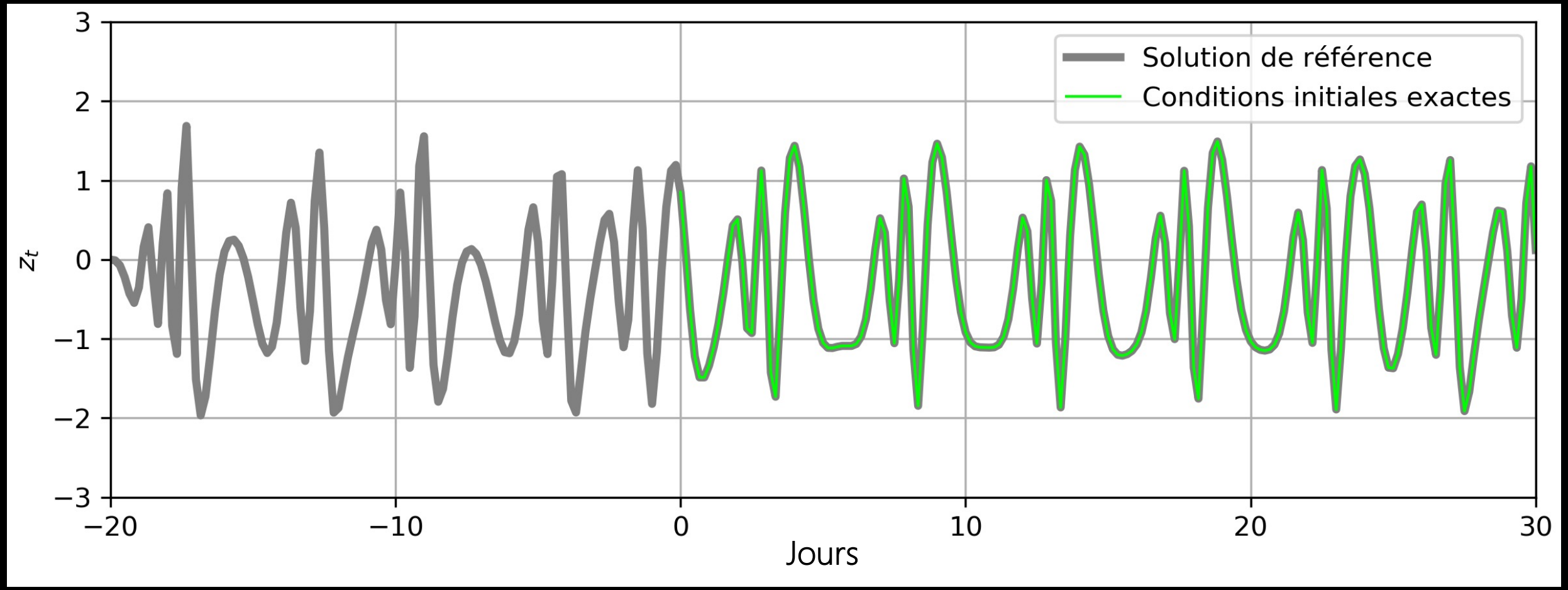


1951-1963

Un dynamique déterministe mais très sensible aux conditions initiales



Un dynamique déterministe mais très sensible aux conditions initiales



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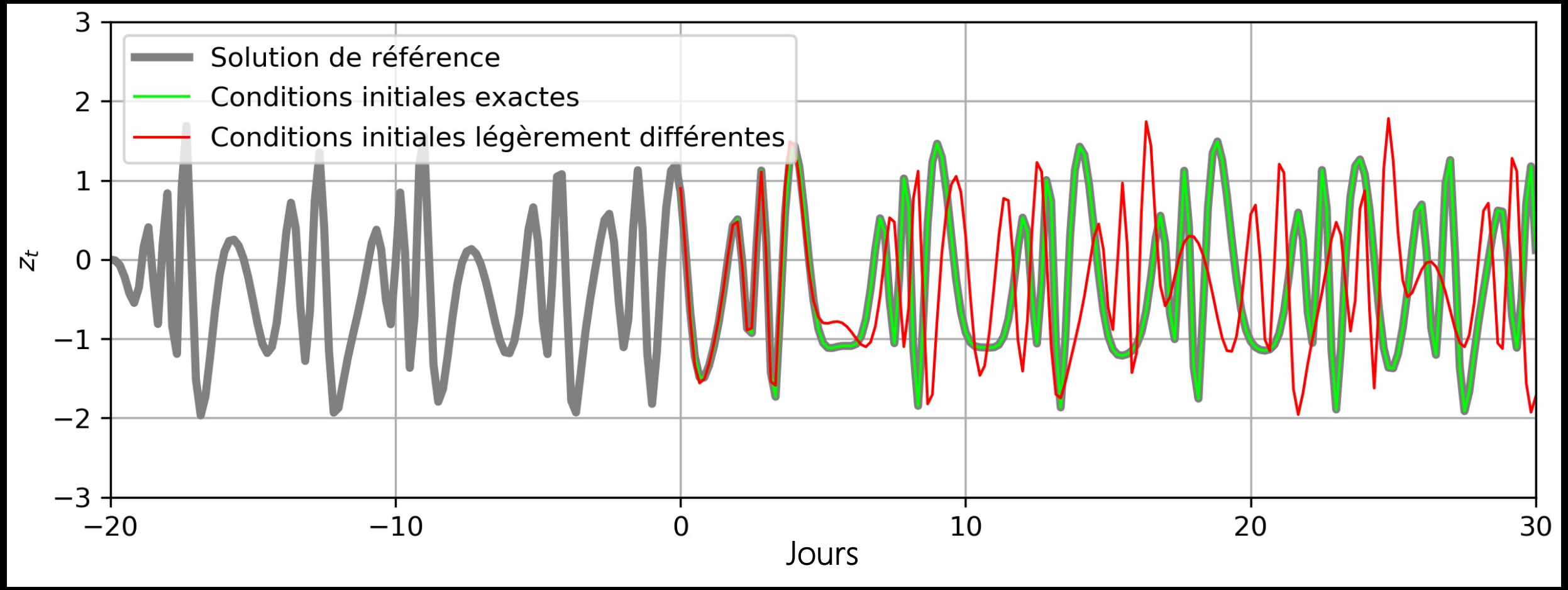

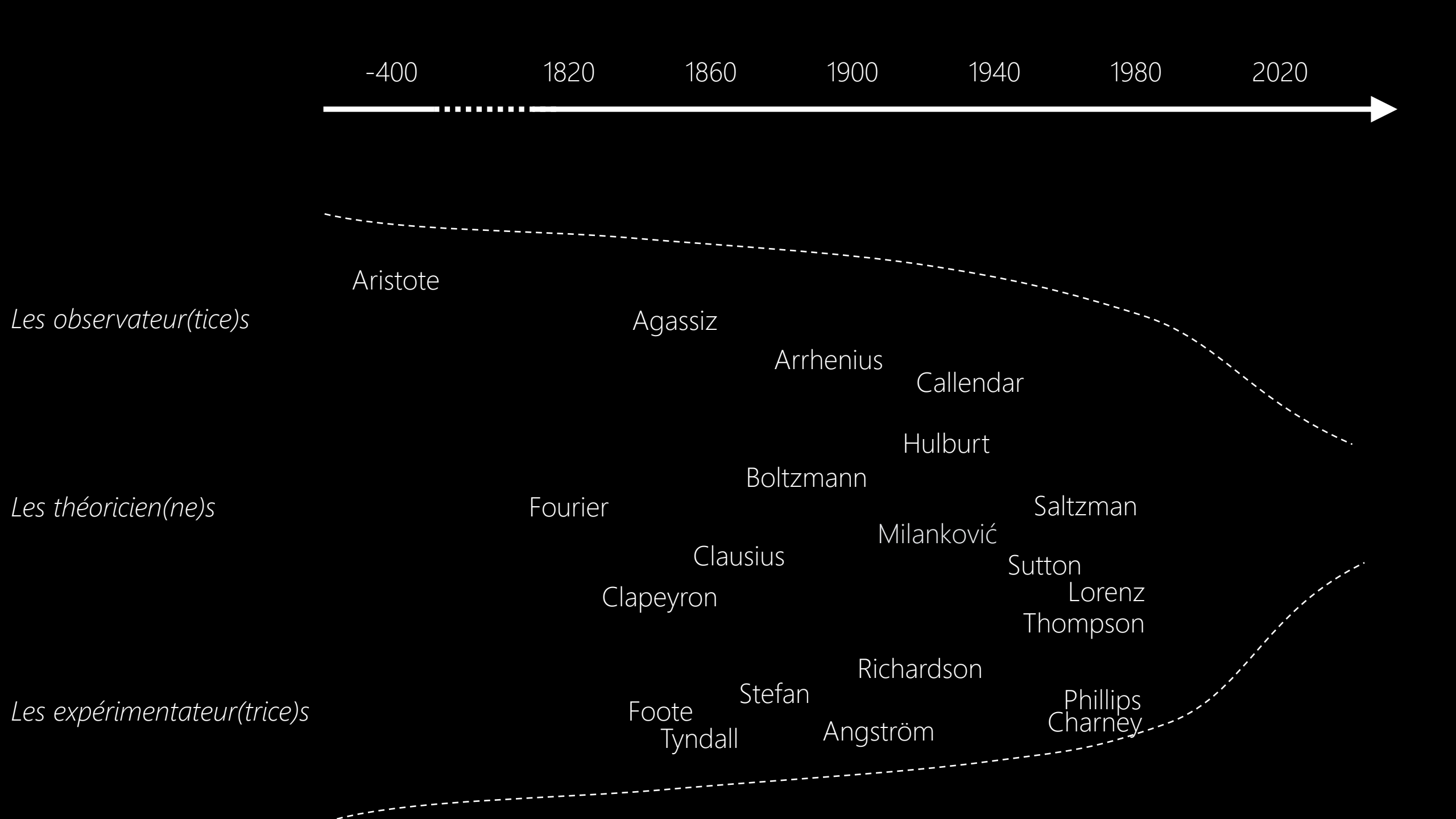
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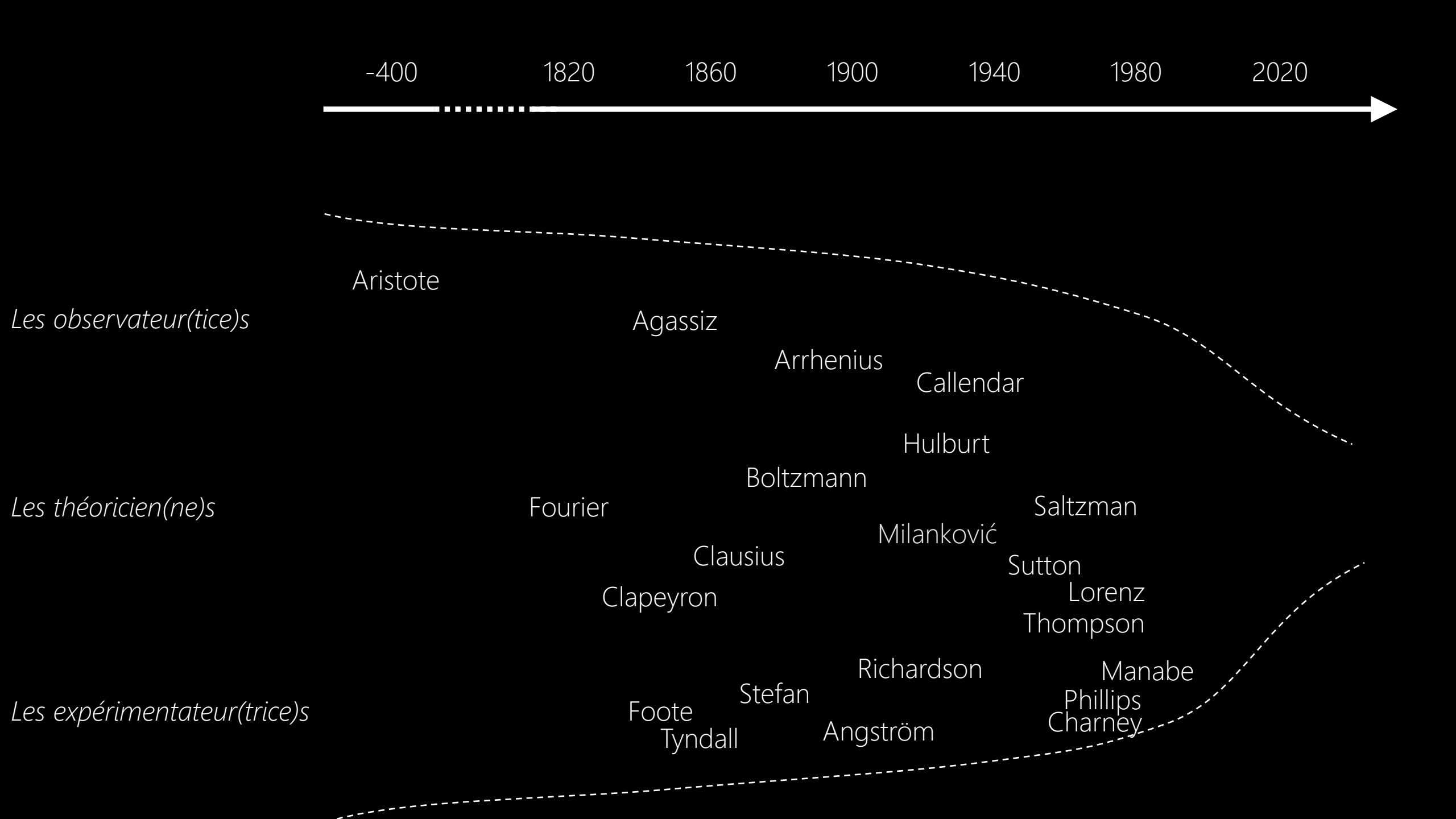
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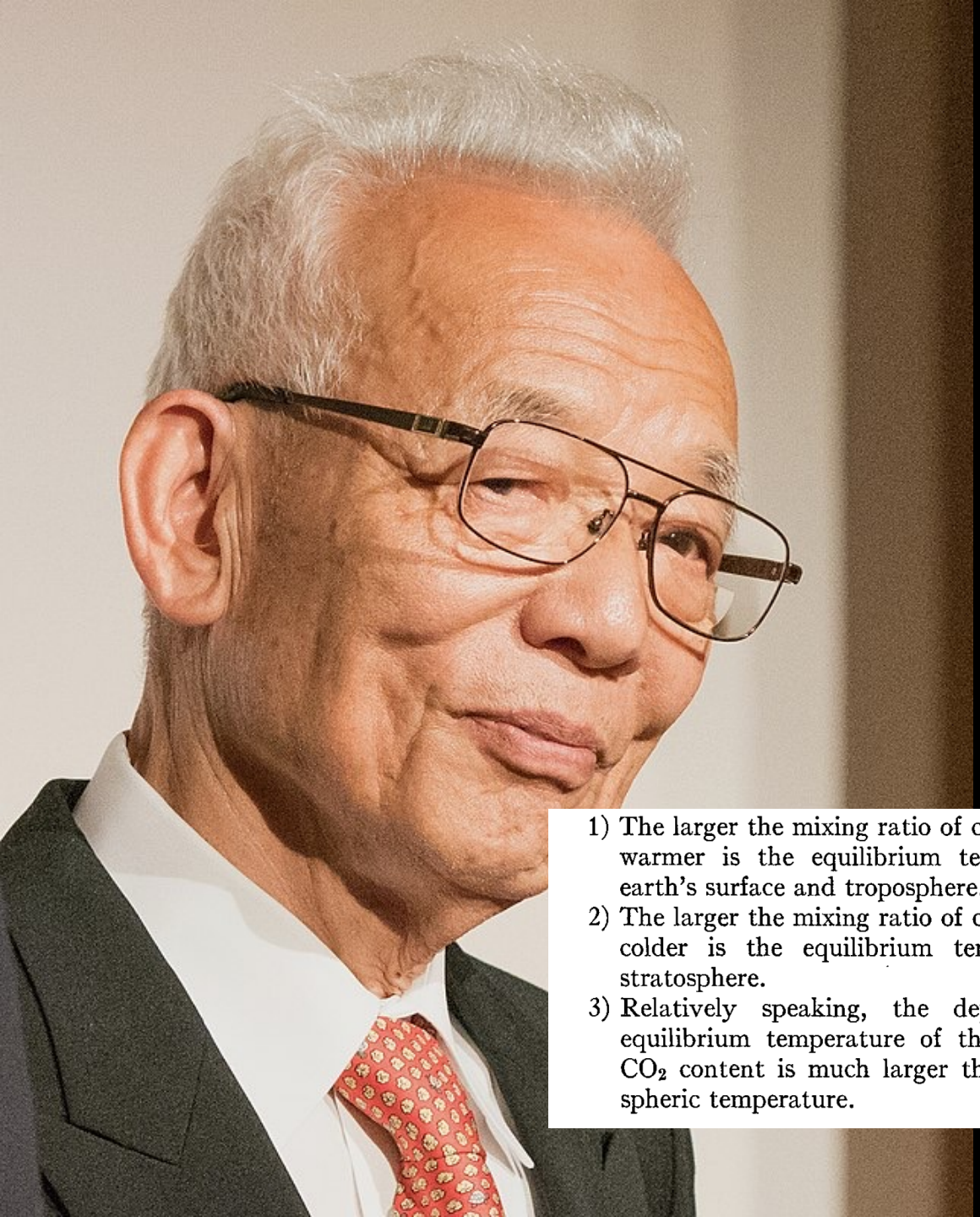
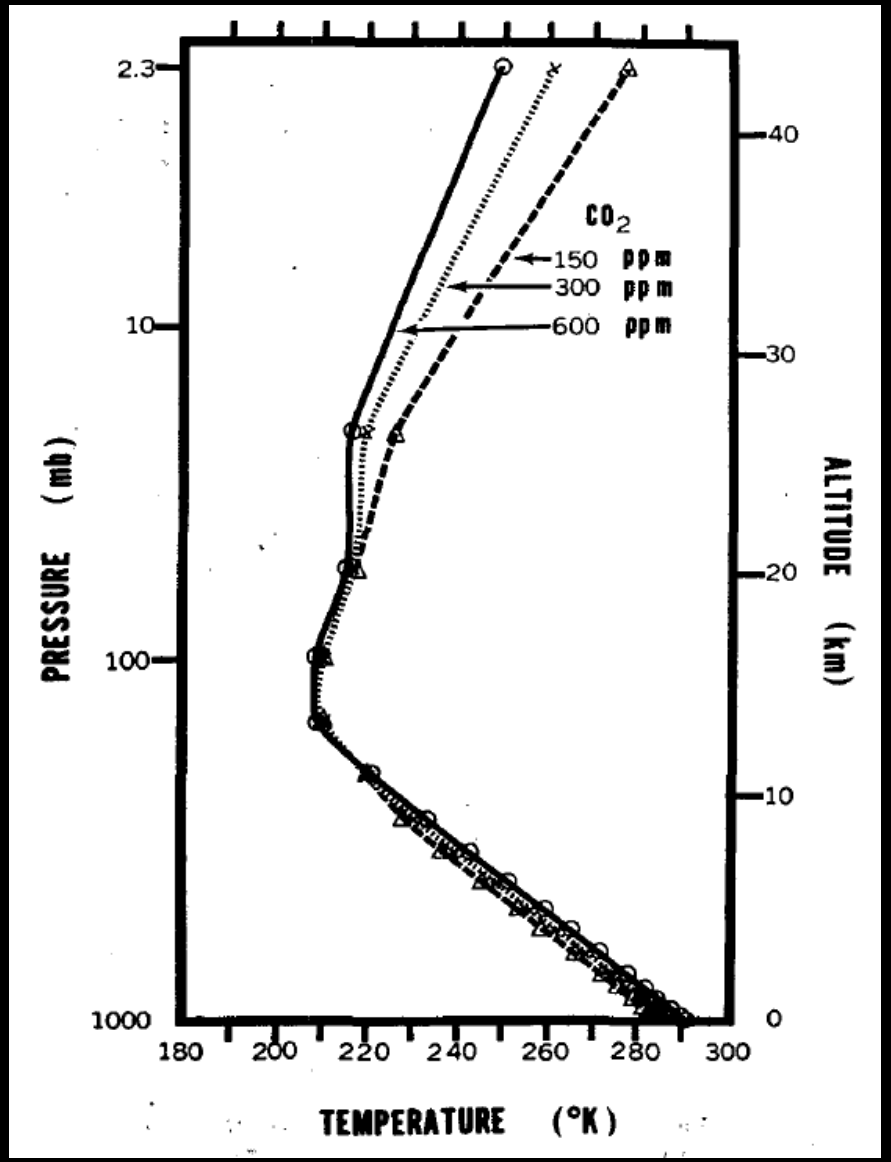
Syukuro Manabe (1931-)



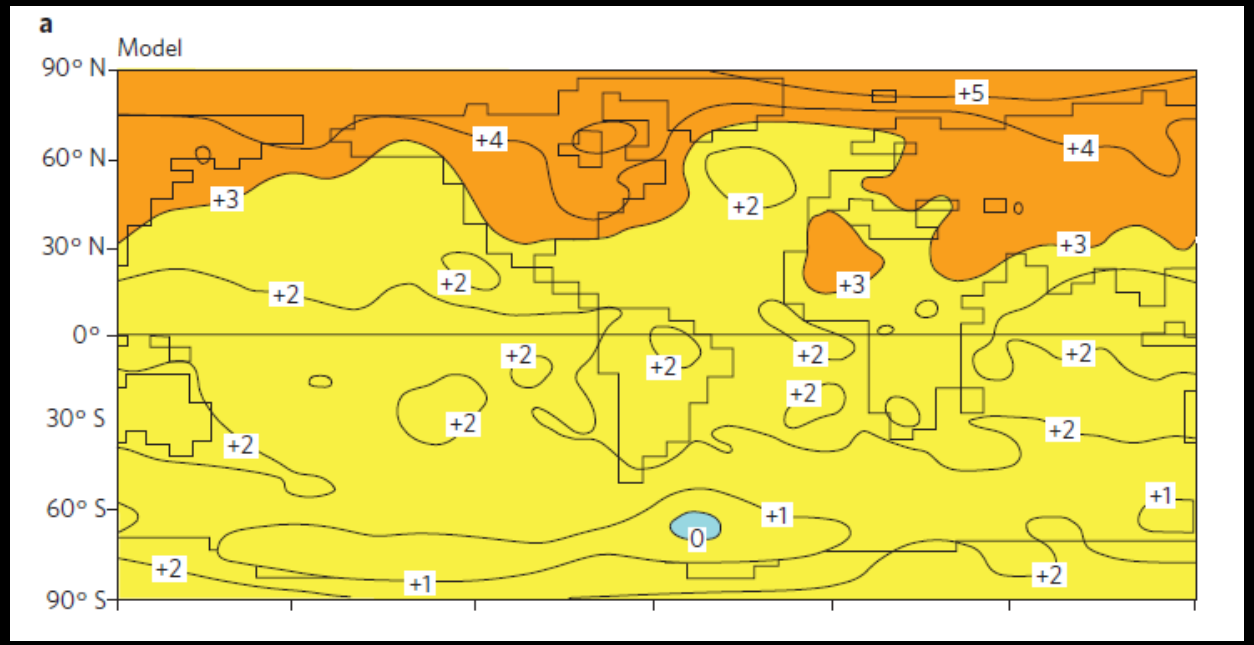
1) The larger the mixing ratio of carbon dioxide, the warmer is the equilibrium temperature of the earth's surface and troposphere.
2) The larger the mixing ratio of carbon dioxide, the colder is the equilibrium temperature of the stratosphere.
3) Relatively speaking, the dependence of the equilibrium temperature of the stratosphere on CO_2 content is much larger than that of tropospheric temperature.



1977

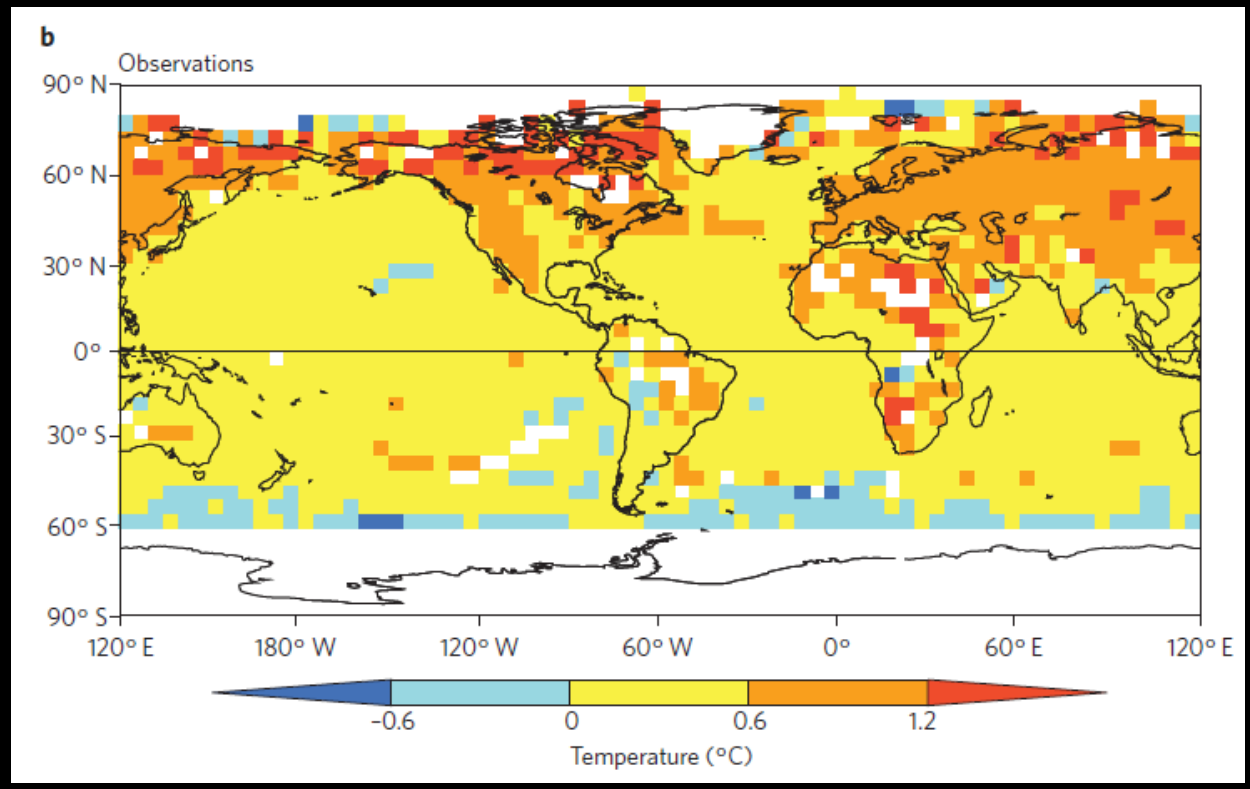
Manabe, S., & Wetherald, R. T. (1967). Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity. Journal of the Atmospheric Sciences, 24(3), 241–259. https://doi.org/10.1175/1520-0469(1967)024<0241:TEOTAW>2.0.CO;2

Réponse en température à une projection 2 x CO_2
(projection réalisée en 1989)

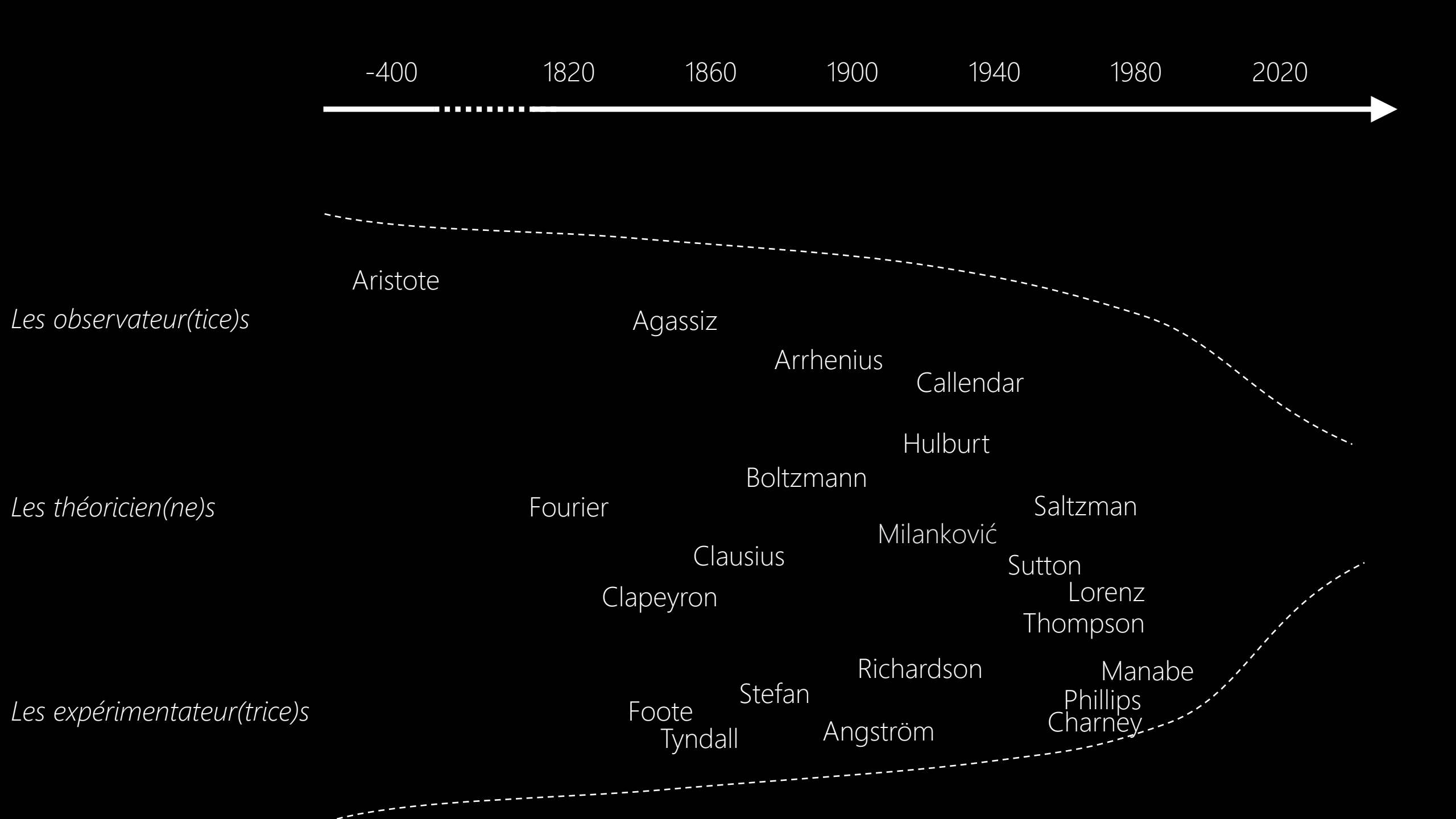


Manabe, S., & Stouffer, R. J. (1980). Sensitivity of a global climate model to an increase of CO_2 concentration in the atmosphere. Journal of Geophysical Research, 85(C10), 5529. https://doi.org/10.1029/JC085iC10p05529

Augmentation de température
1991-2015 moins 1961-1990



Stouffer, Ronald J., and Syukuro Manabe. "Assessing Temperature Pattern Projections Made in 1989." Nature Climate Change 7, no. 3 (March 2017): 163–65. https://doi.org/10.1038/nclimate3224.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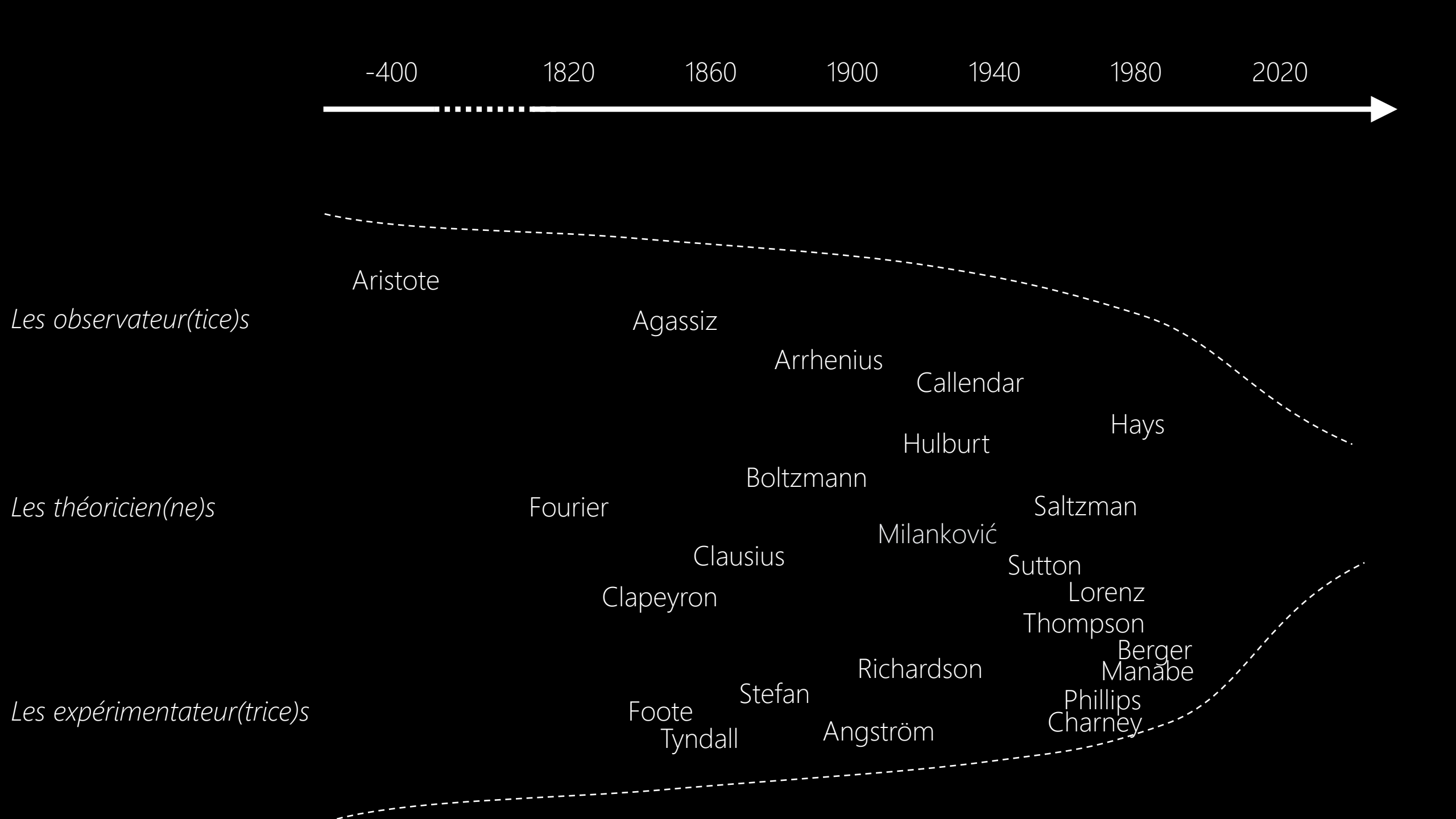
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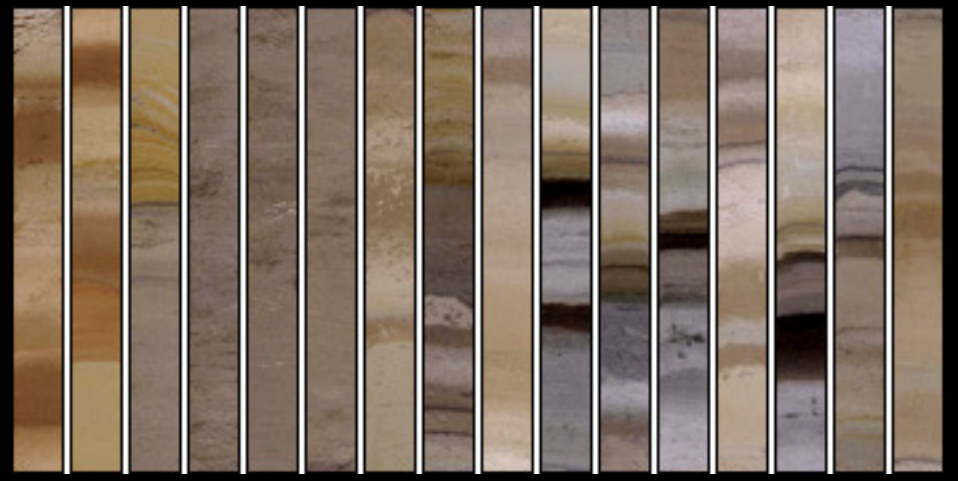
Tyndall
Angström

James D. Hays (1926-)



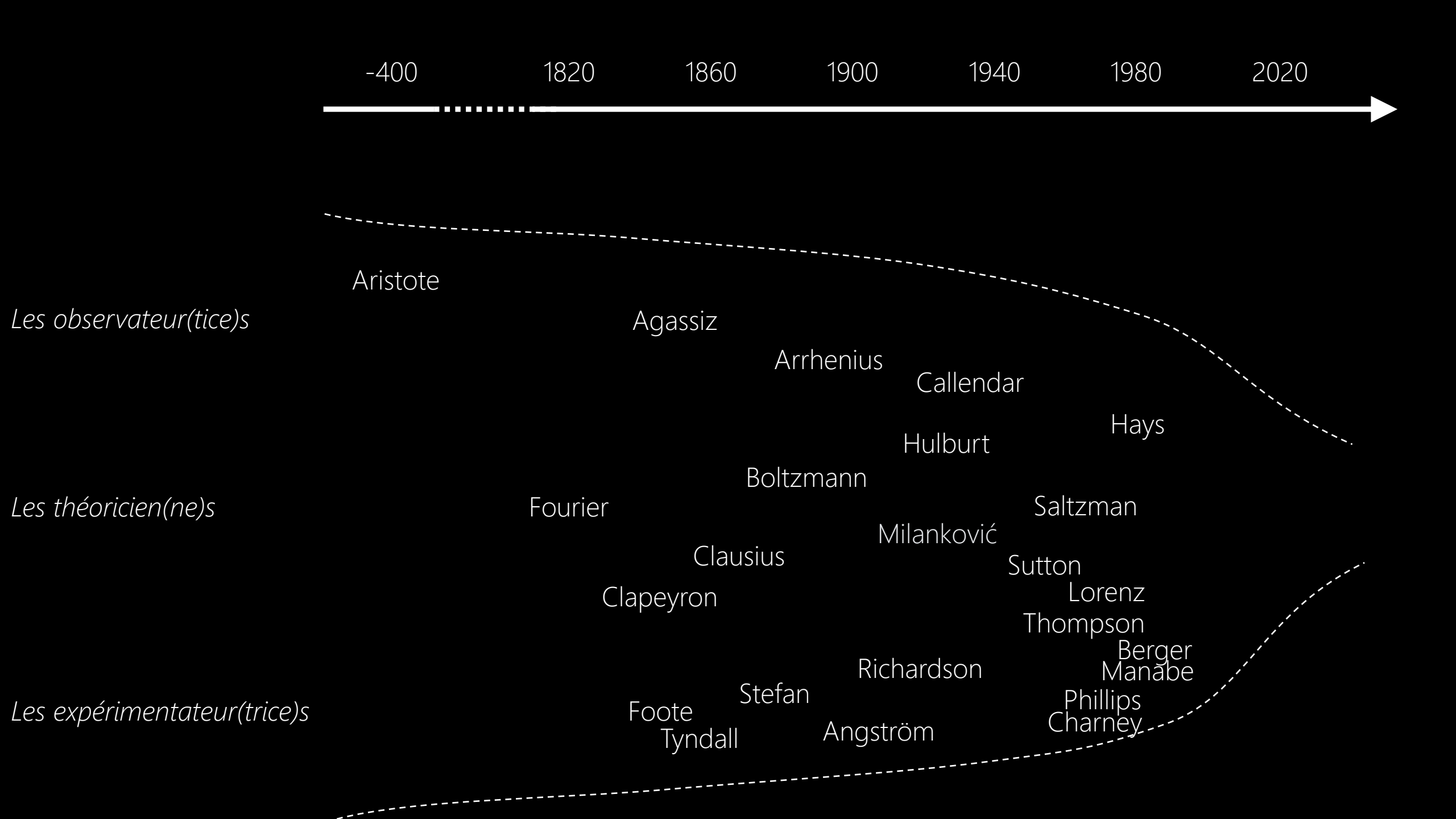
Hays, J. D., Imbrie, J., & Shackleton, N. J. (1976). Variations in the Earth's Orbit: Pacemaker of the Ice Ages. Science, 194(4270), 1121–1132. https://doi.org/10.1126/science.194.4270.1121

André Berger (1942-)

$$
\begin{aligned}
e &= e_0 + \Sigma\, E_i \cos(\lambda_i t + \phi_i) \\
e \sin\tilde{\omega} &= \Sigma\, P_i \sin(\alpha_i t + \beta_i) \\
\varepsilon &= \bar{\varepsilon} + \Sigma\, A_i \cos(\gamma_i t + \delta_i)
\end{aligned}
$$

1976-1977

Berger, A. L. (1977). Support for the astronomical theory of climatic change. Nature, 269(5623), 44–45. https://doi.org/10.1038/269044a0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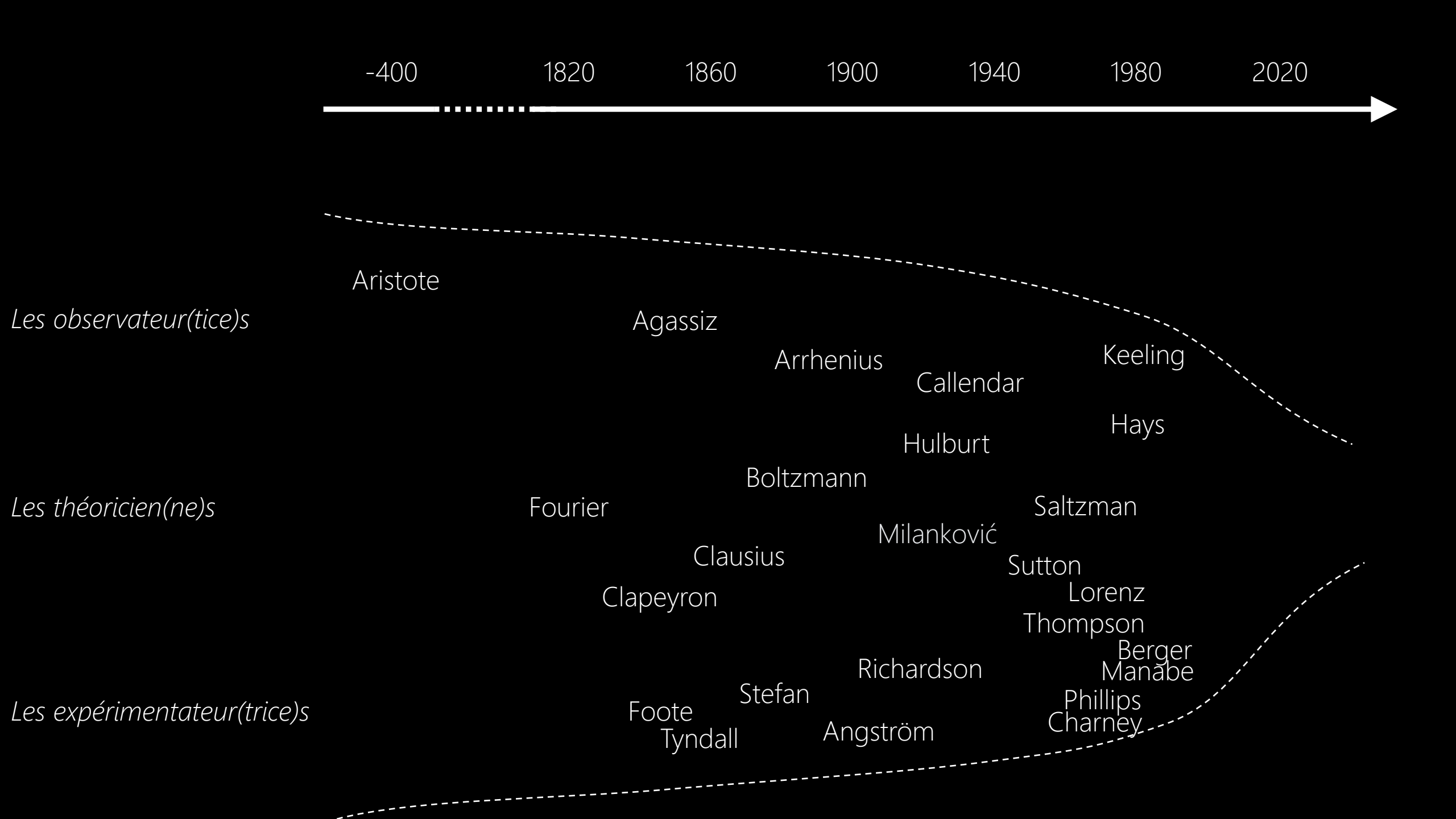
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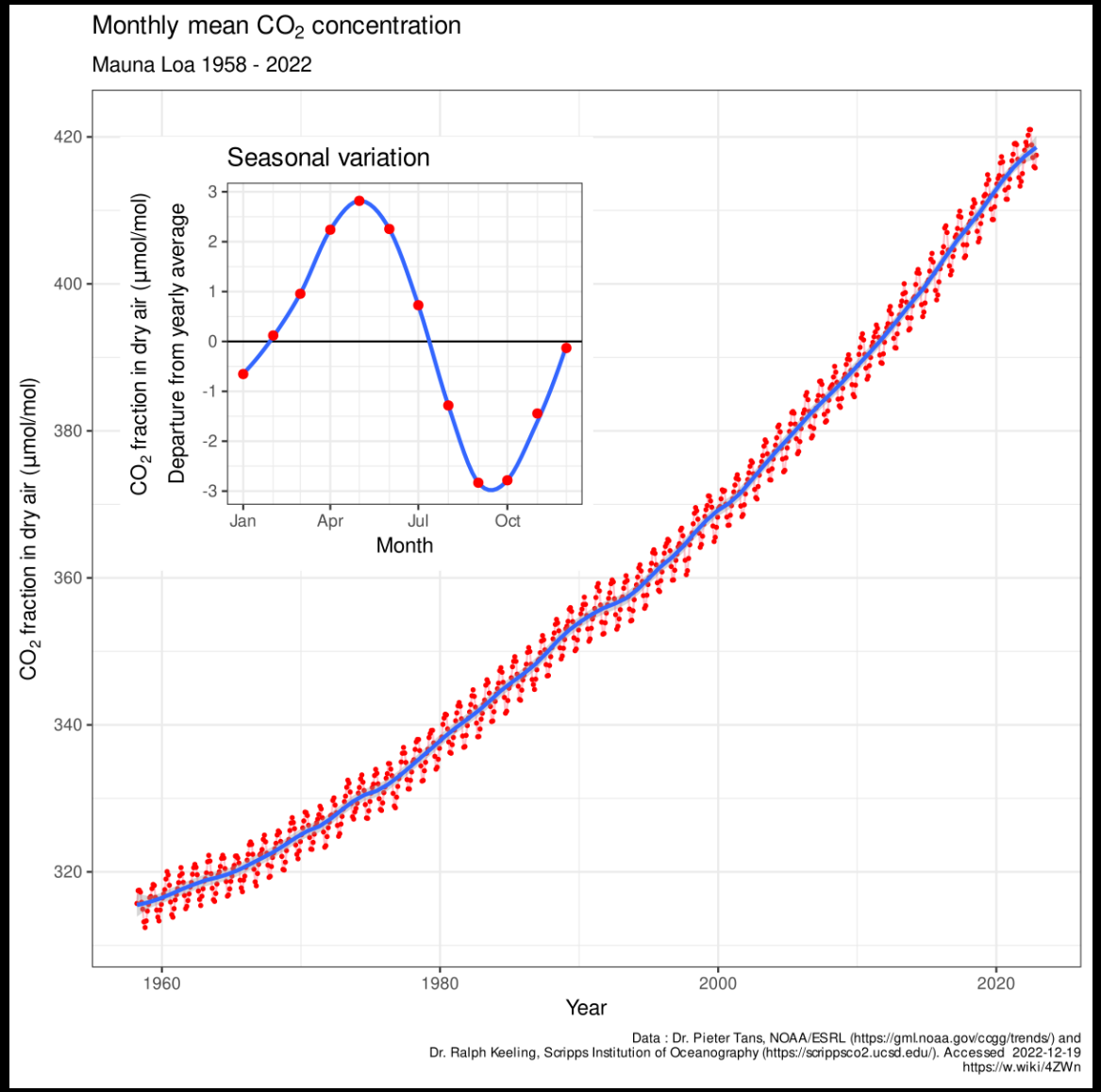
Charles Keeling (1928-2005)



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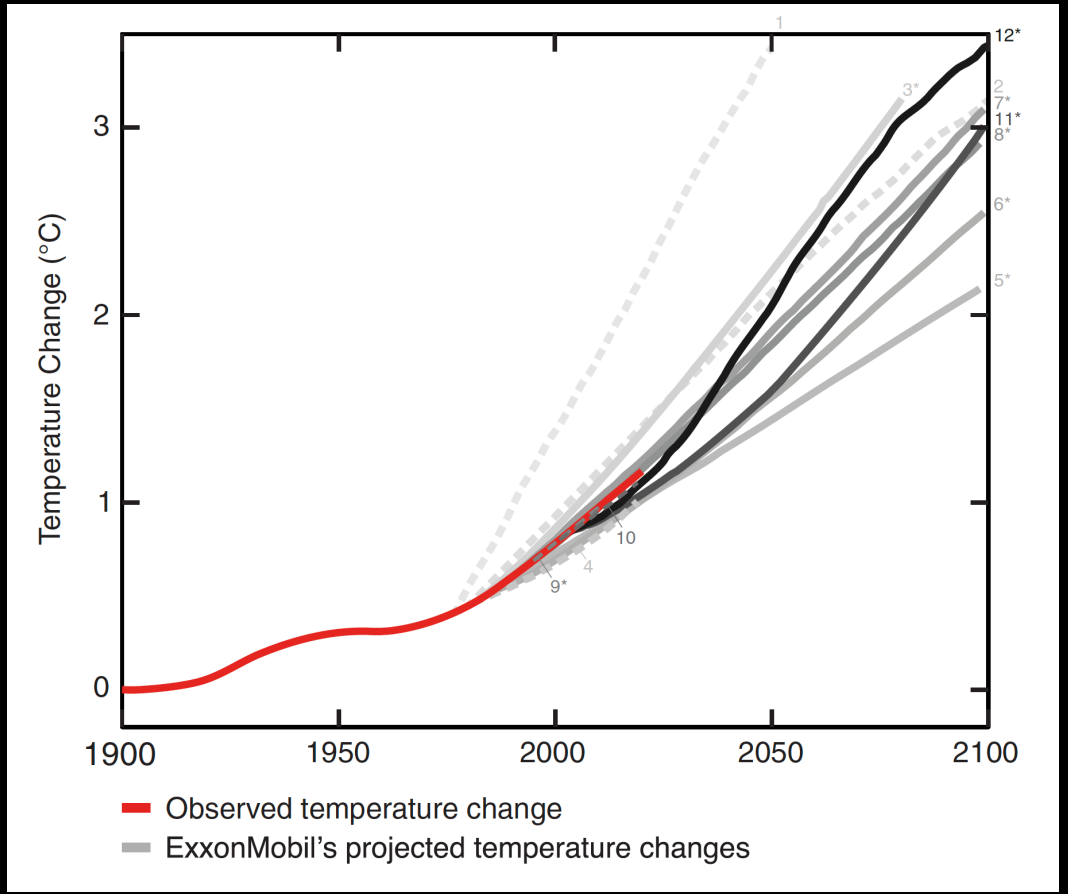
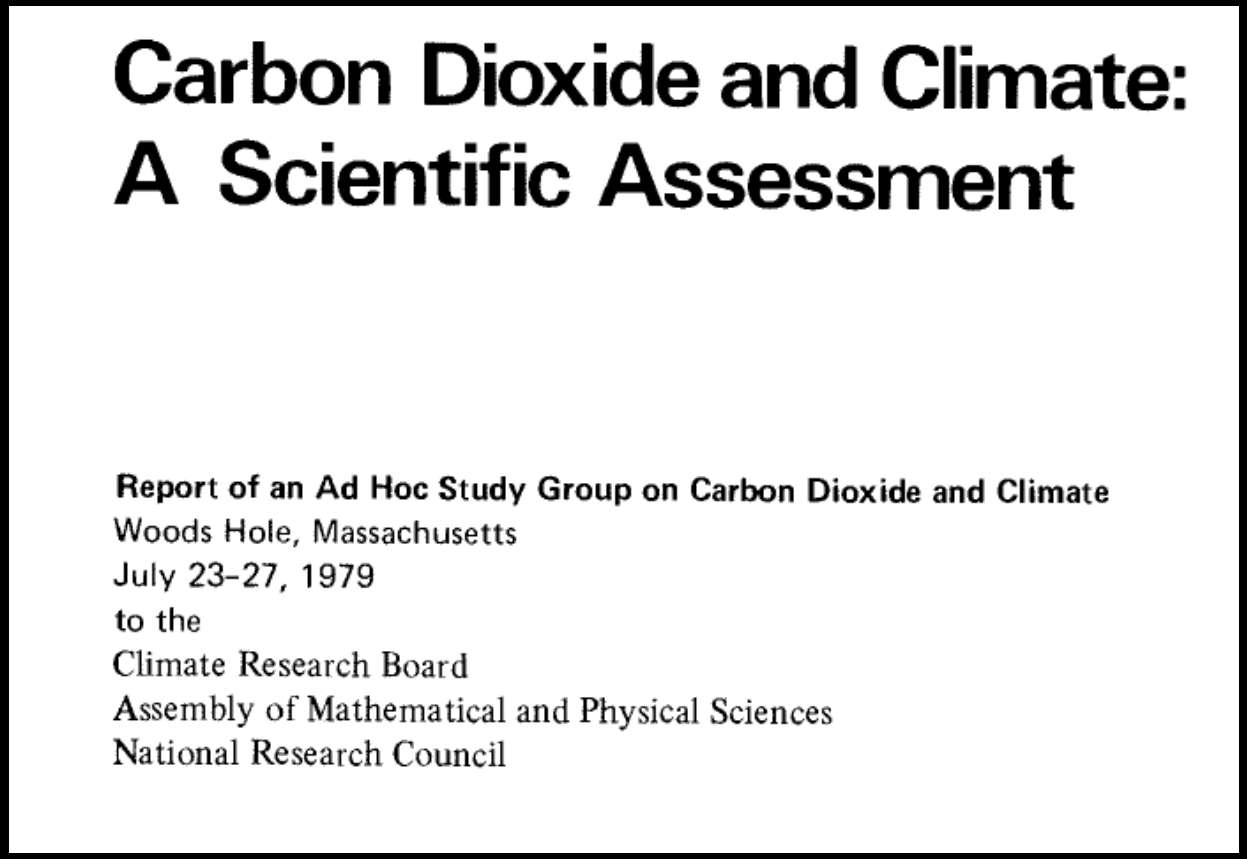
ExxonMobil



Supran, G., Rahmstorf, S., & Oreskes, N. (2023). Assessing ExxonMobil's global warming projections. Science, 379(6628), eabk0063. https://doi.org/10.1126/science.abk0063

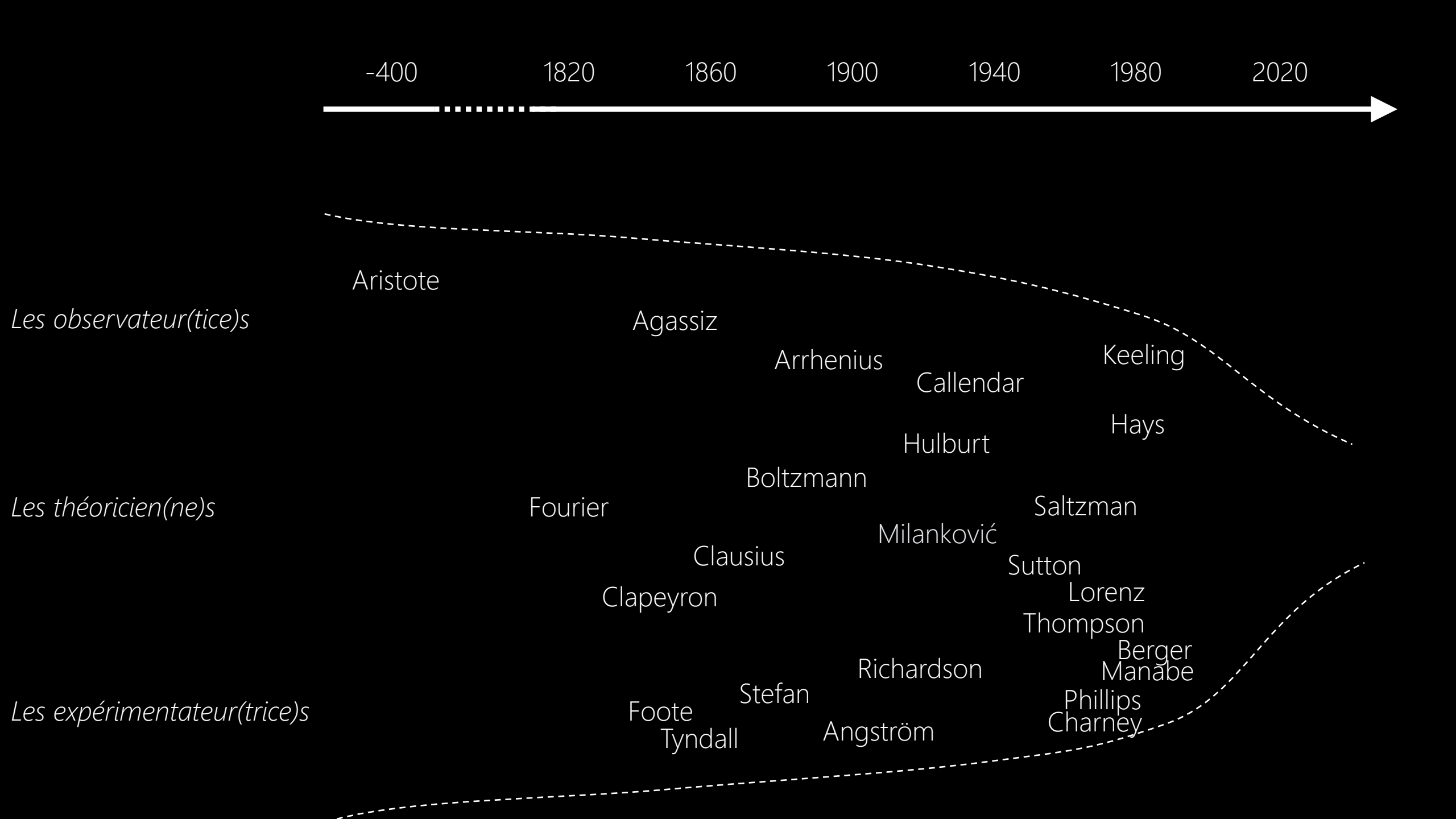
1977



Rapport Charney

« Nous avons désormais la preuve irréfutable que l'atmosphère est en train de changer et que nous contribuons nous-mêmes à ces changements »

1979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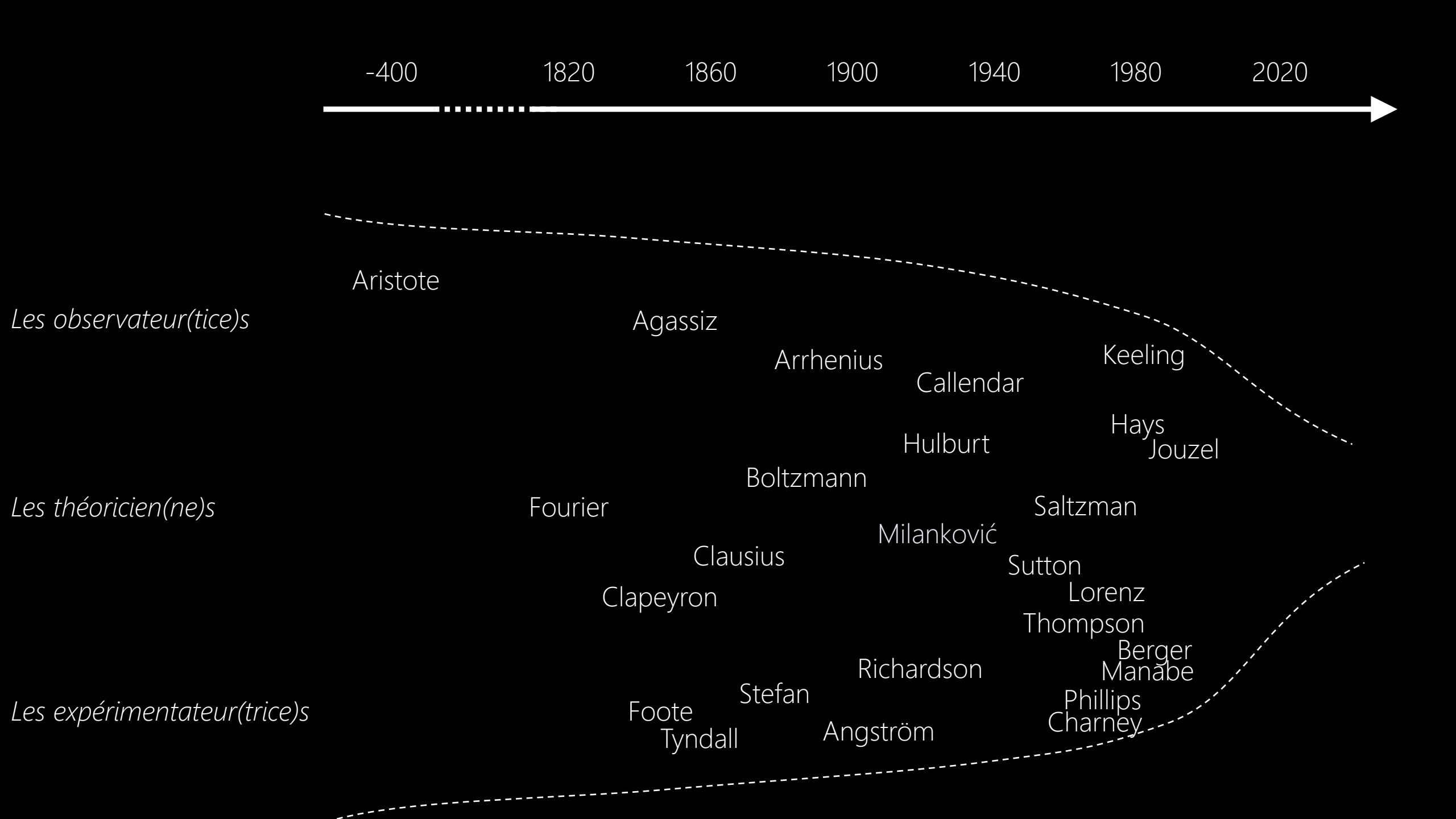
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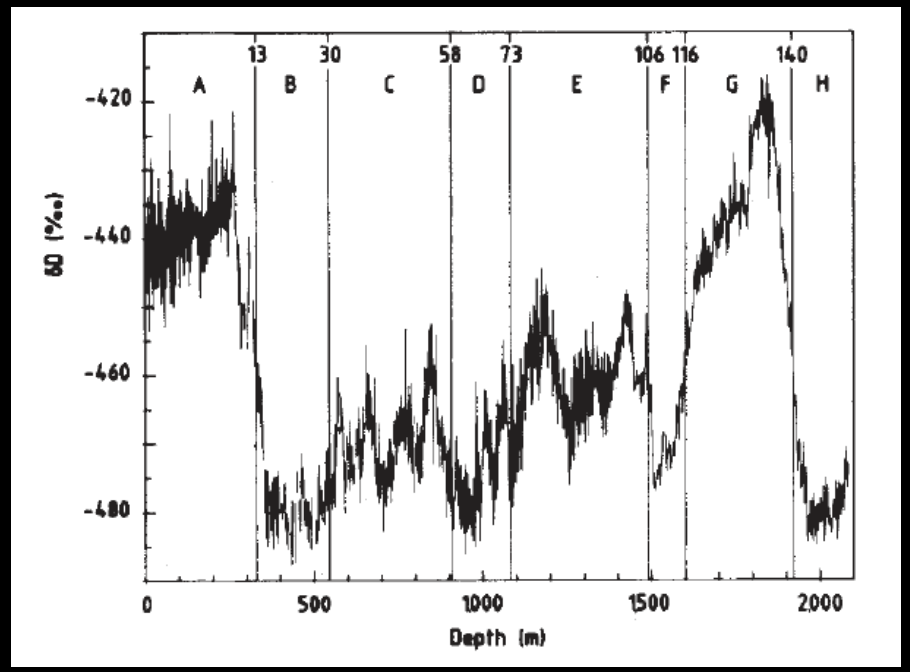
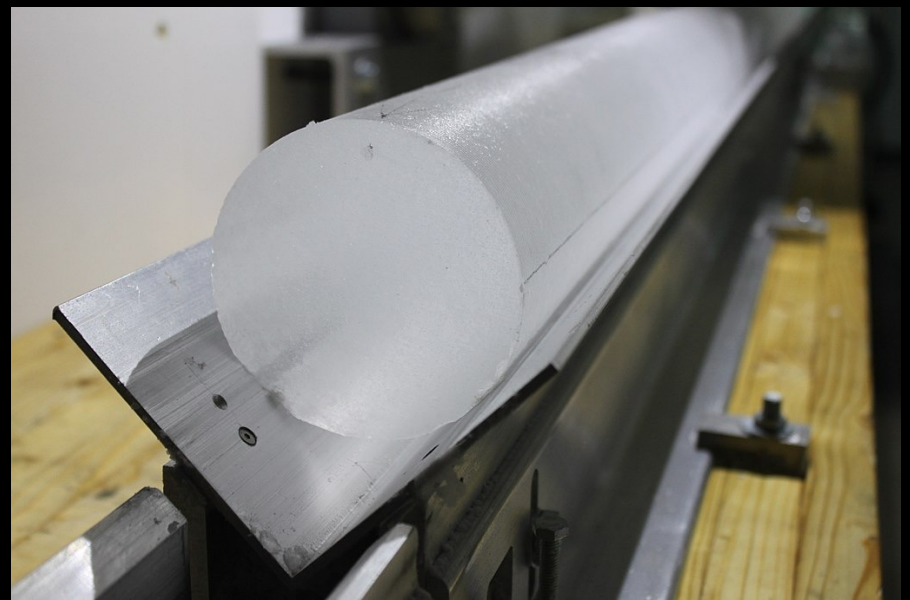
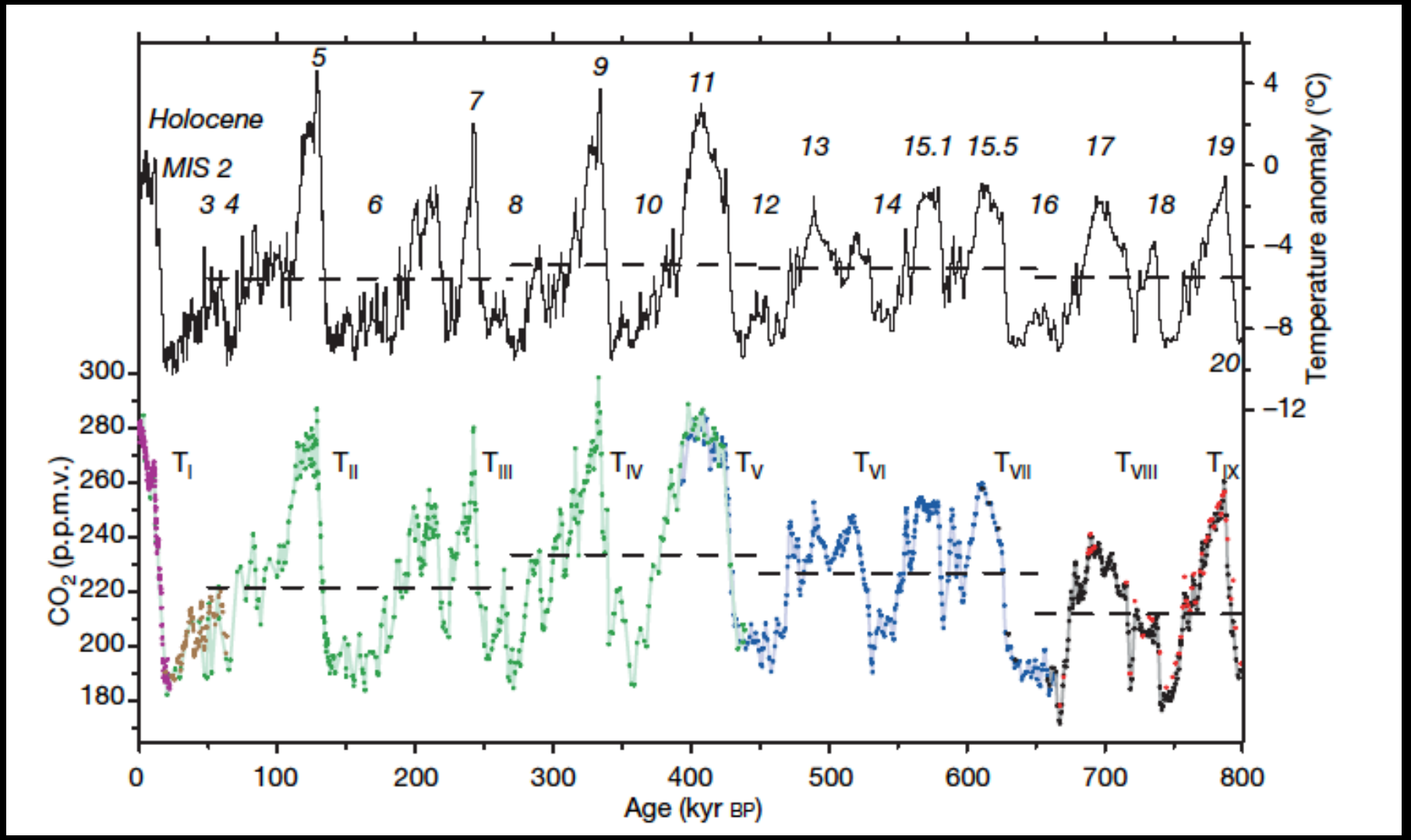
Jean Jouzel (1947-)



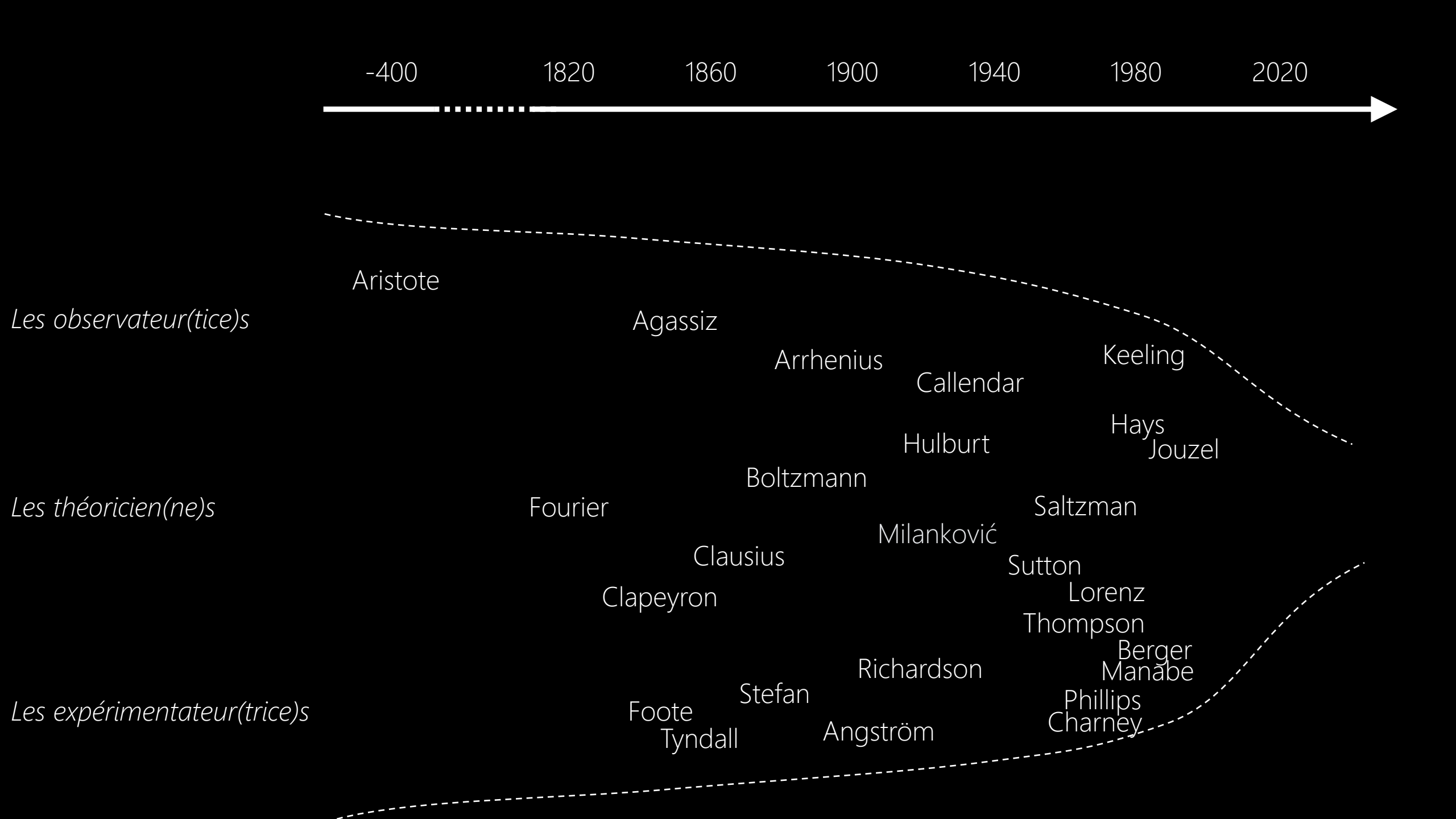


Jouzel, J., Lorius, C., Petit, J. R., Genthon, C., Barkov, N. I., Kotlyakov, V. M., & Petrov, V. M. (1987). Vostok ice core: A continuous isotope temperature record over the last climatic cycle (160,000 years). Nature, 329(6138), Article 6138. https://doi.org/10.1038/329403a0



Lüthi, D., Le Floch, M., Bereiter, B., Blunier, T., Barnola, J.-M., Siegenthaler, U., Raynaud, D., Jouzel, J., Fischer, H., Kawamura, K., & Stocker, T. F. (2008). High-resolution carbon dioxide concentration record 650,000–800,000 years before present. Nature, 453(7193), Article 7193. https://doi.org/10.1038/nature06949

Rapports du GIEC (1992, 1996, 2001, 2007, 2014, 2022)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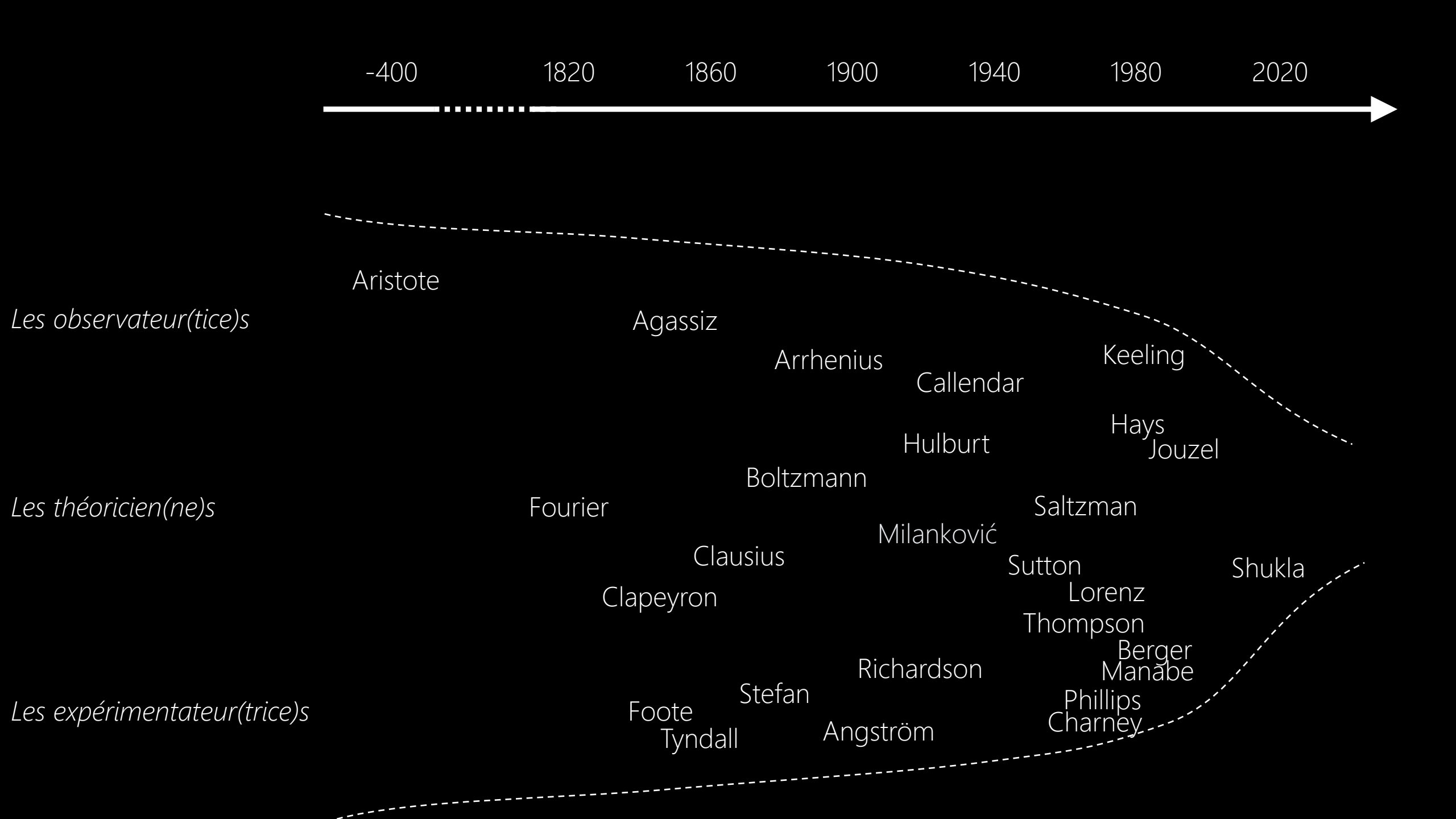
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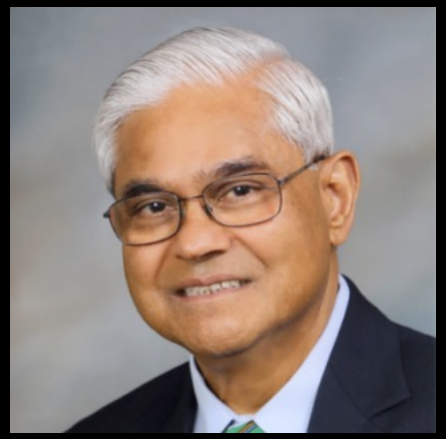
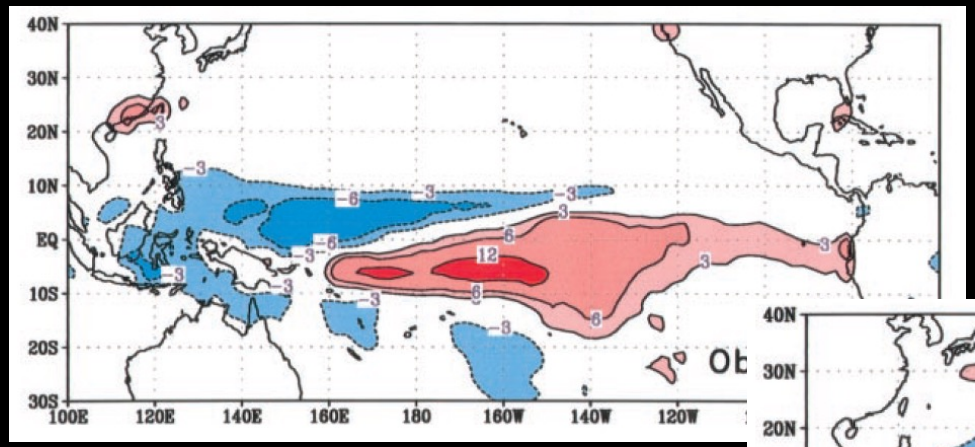
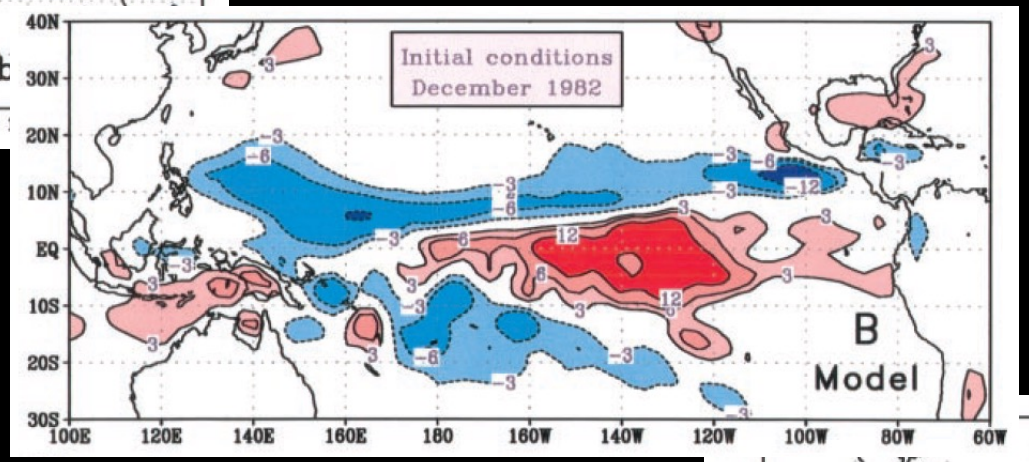
Quand météo et deviennent un seul et même problème



Jagadish Shukla (1944-)

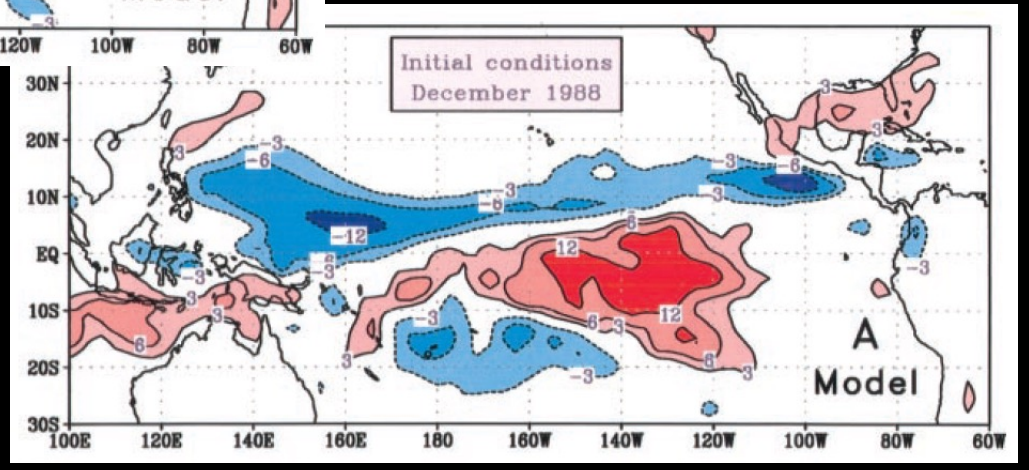


Anomalies de précipitations observées en hiver 1983



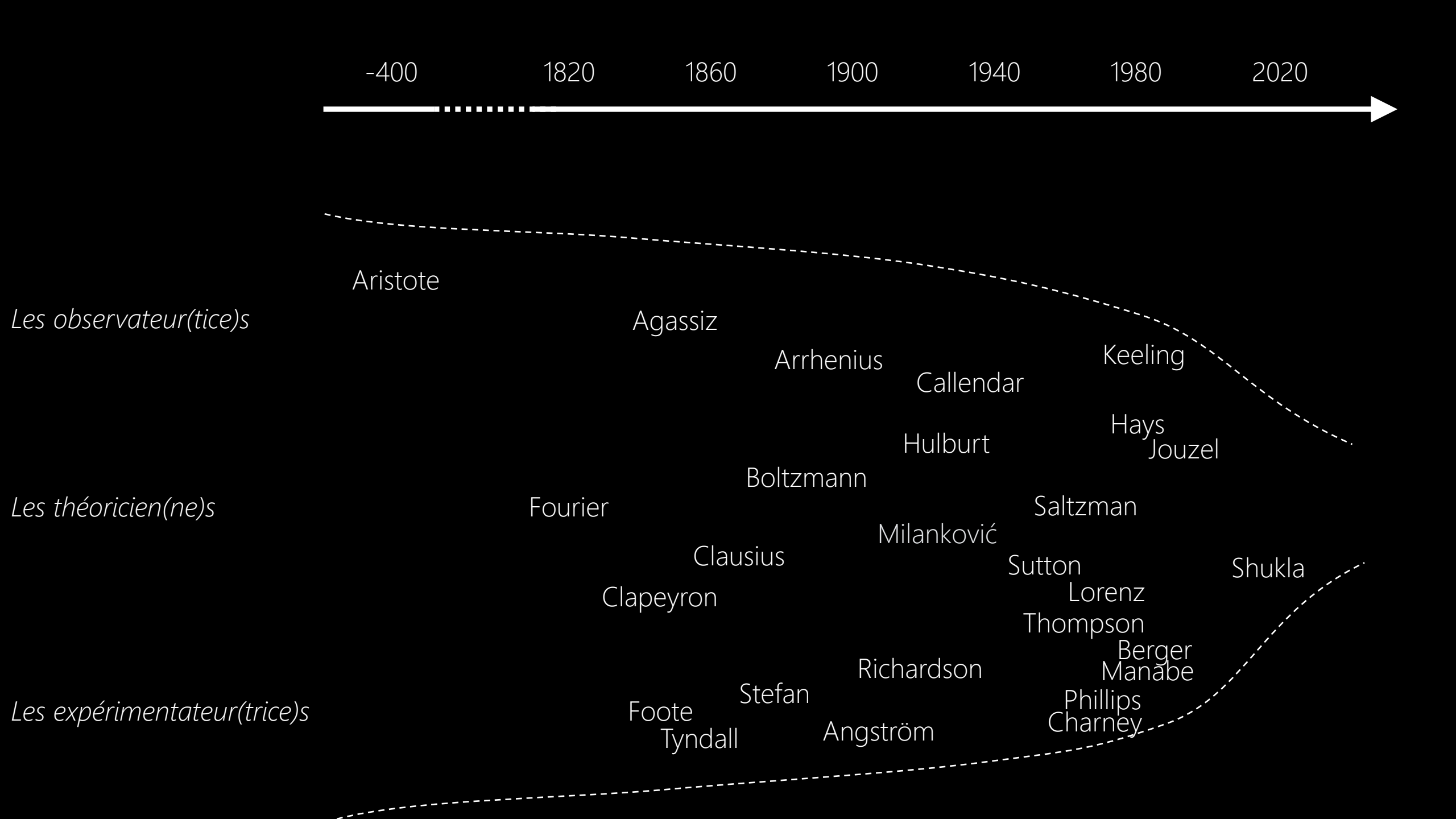
Prévision d'un modèle avec conditions initiales atmosphériques de fin 1982

Prévision d'un modèle avec conditions initiales atmosphériques de fin <u>1988</u>



1998

Shukla, J. "Predictability in the Midst of Chaos: A Scientific Basis for Climate Forecasting." *Science* 282, no. 5389 (October 23, 1998): 728–31. https://doi.org/10.1126/science.282.5389.728.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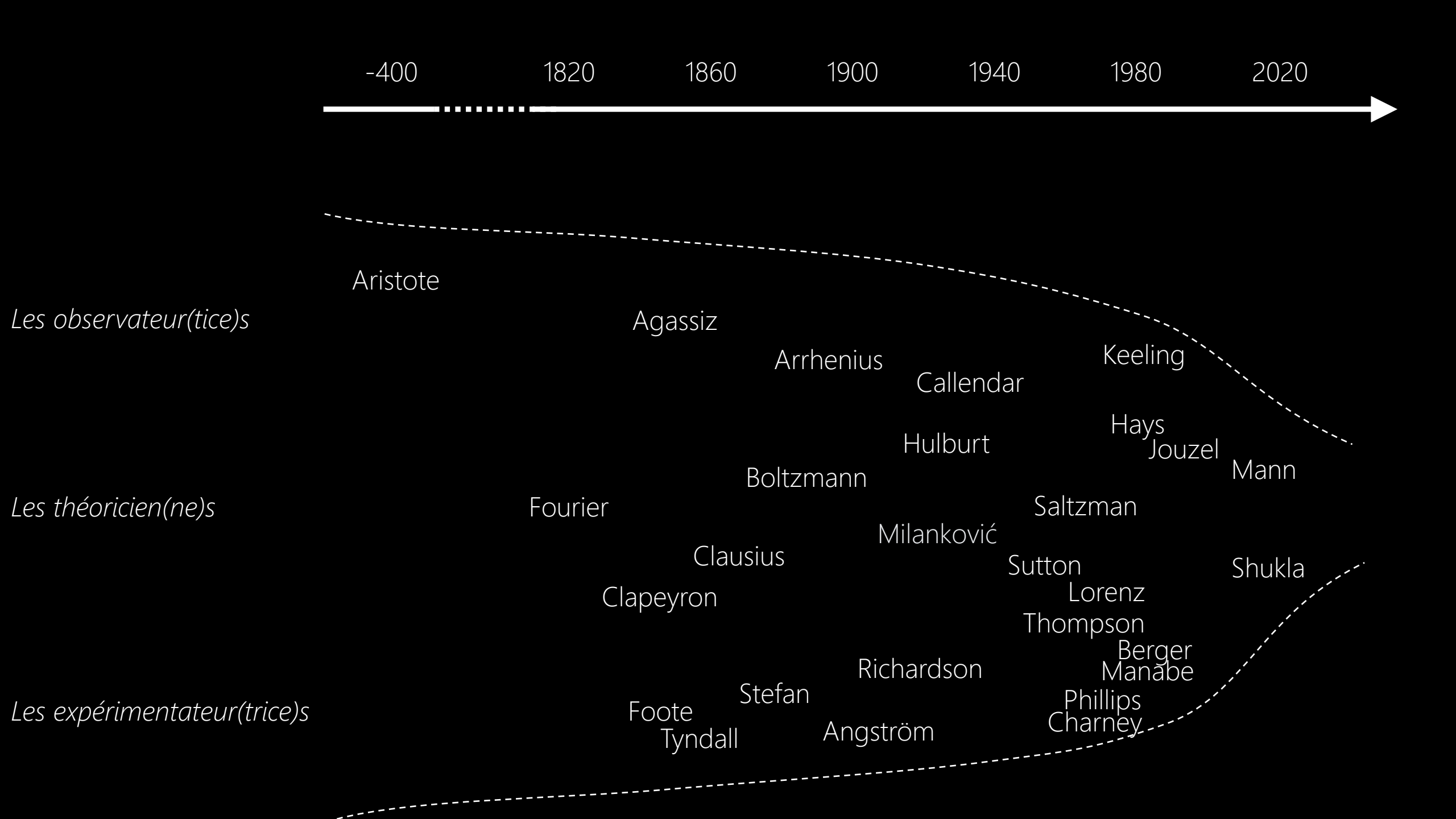
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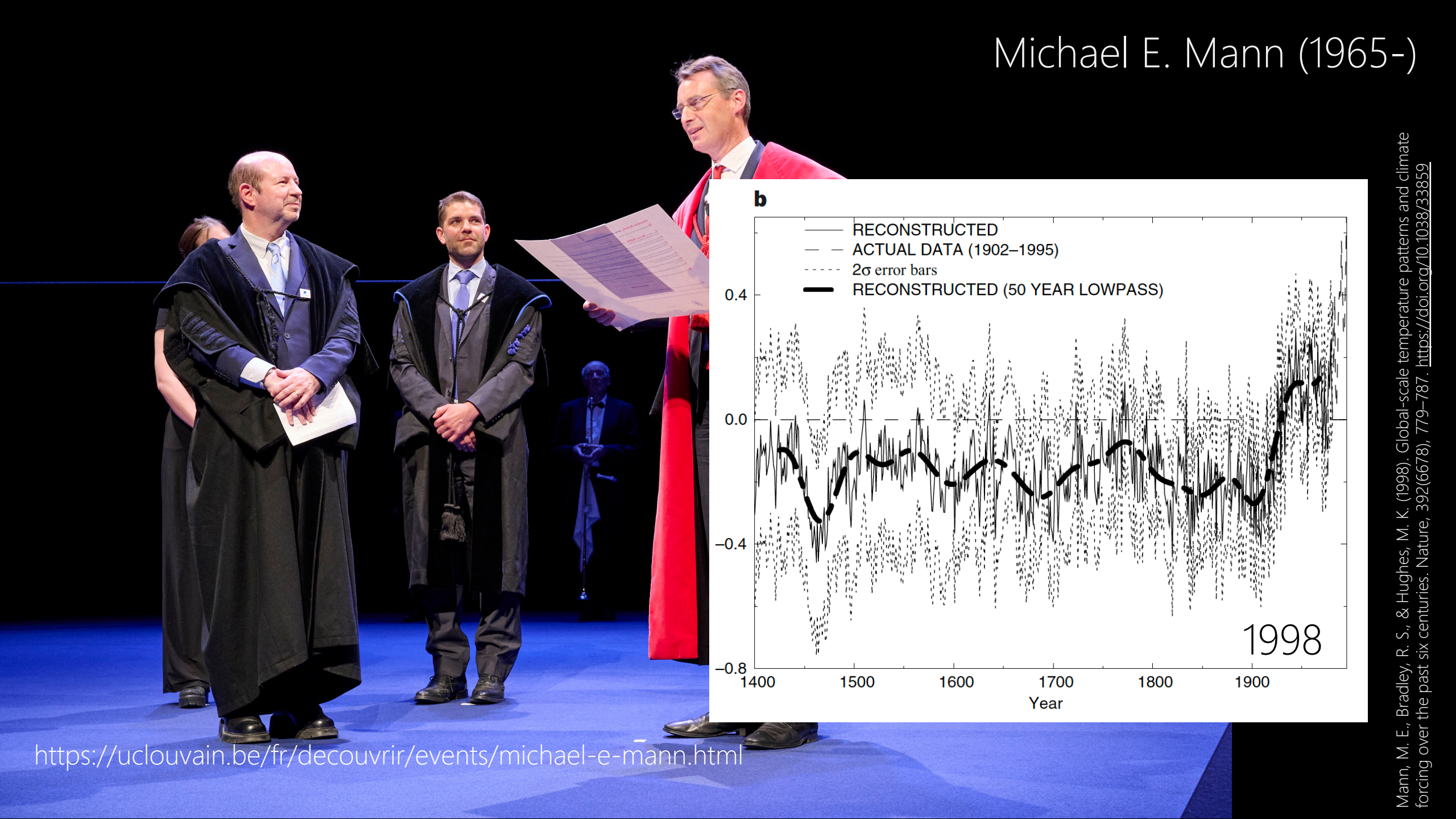
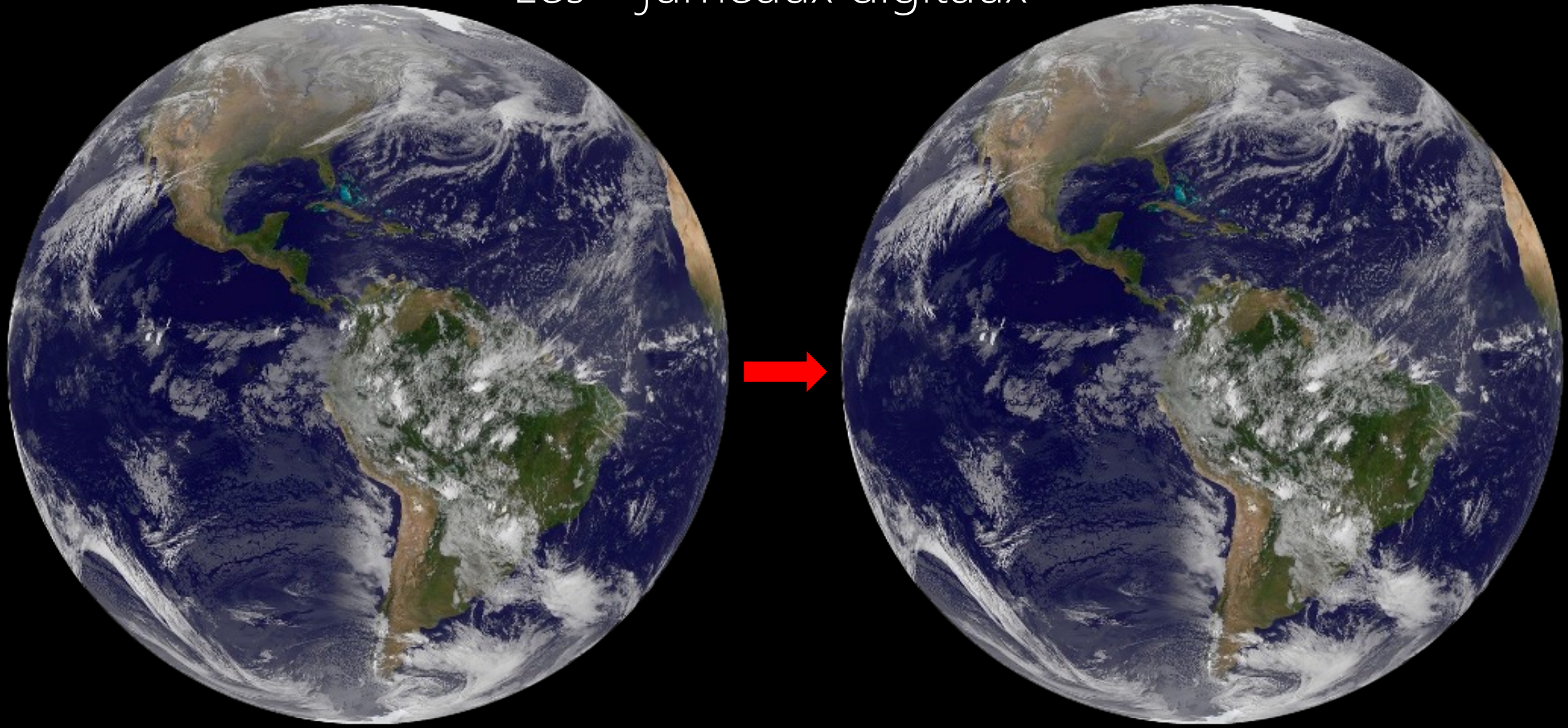
Michael E. Mann (1965-)



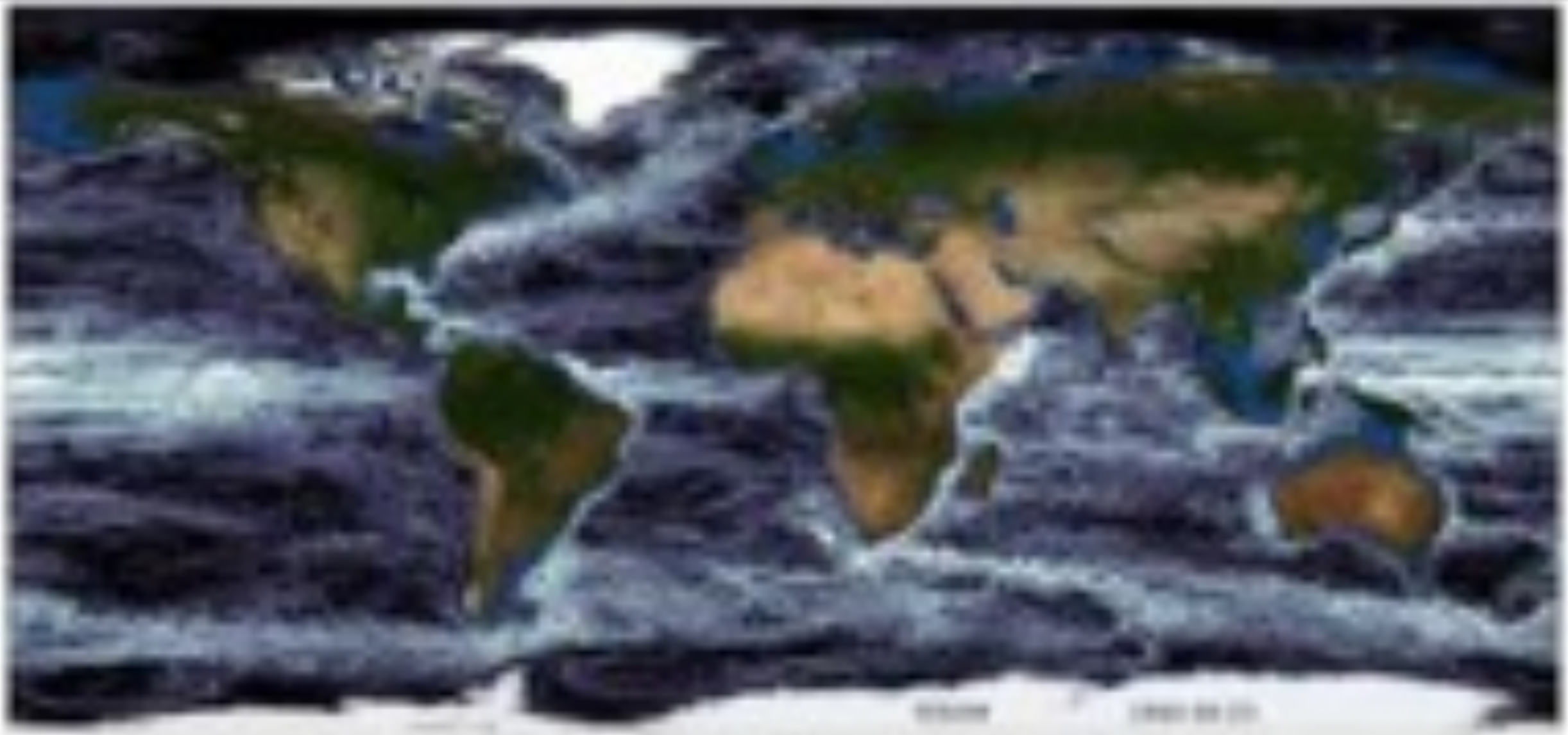
https://uclouvain.be/fr/decouvrir/events/michael-e-mann.html

Mann, M. E., Bradley, R. S., & Hughes, M. K. (1998). Global-scale temperature patterns and climate forcing over the past six centuries. Nature, 392(6678), 779–787. https://doi.org/10.1038/33859

Les « jumeaux digitaux »



« La Terre vue par la Commission Européenne »



200 ans sciences du climat

- Observation, théorie, expérimentation: trois lignes convergentes
- Des découvertes de plus en plus collectives
- Toujours de grandes questions en suspens

Vous pouvez trouver cette présentation ici

Références

- Podcast « L'heure du Monde: qui aurait pu prédire la crise climatique? » → https://open.spotify.com/episode/6nQDOiYn0ArrIUkyq5GlXj?si=03d6dd715217452c
- https://en.wikipedia.org/wiki/History_of_climate_change_science
- https://scied.ucar.edu/learning-zone/how-climate-works/history-climate-science-research
- https://www.ipcc.ch/site/assets/uploads/2018/03/ar4-wg1-chapter1.pdf
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- https://www.discover.ukri.org/a-brief-history-of-climate-change-discoveries/index.html
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- https://www.youtube.com/watch?v=oqu5DjzOBF8
- https://www.youtube.com/watch?v=rXlEcth5Gxc