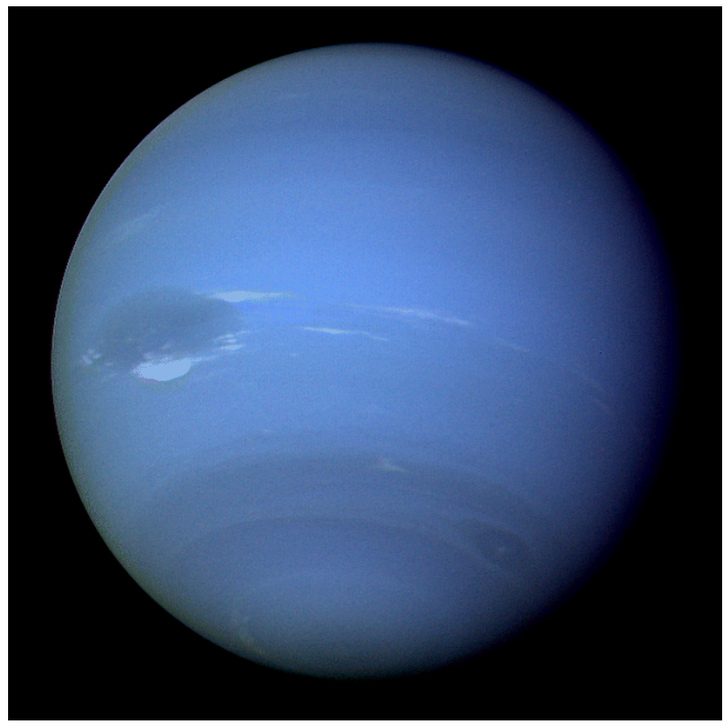
That star is not on the map



Davor Krajnović
Leibniz Institut für Astrophysik Potsdam (AIP)

A famous case

- a story worth a TV mini-series
- a theoretical prediction which turned to be "spot on"
- an example of how science discoveries (really) happen
- a story of success and failure
- a story of rivalry
  - young vs established
  - England vs France
  - Cambridge vs the world
- a scandalous affair
- a conspiracy theory
- and it is still not told fully

Airy's collection of documents related to the discovery of Neptune, the Neptune File in the archives of the Royal Cambridge Observatory (University Library Cambridge) "Missing" from the archive from 1961-1999.

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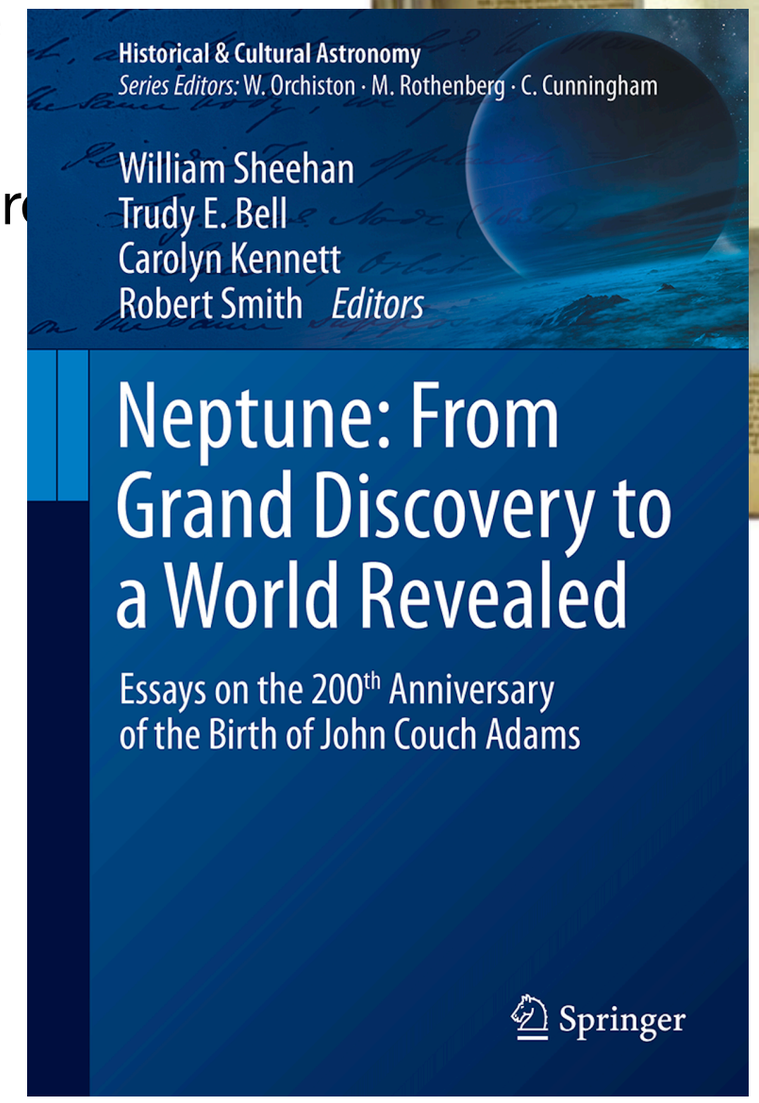

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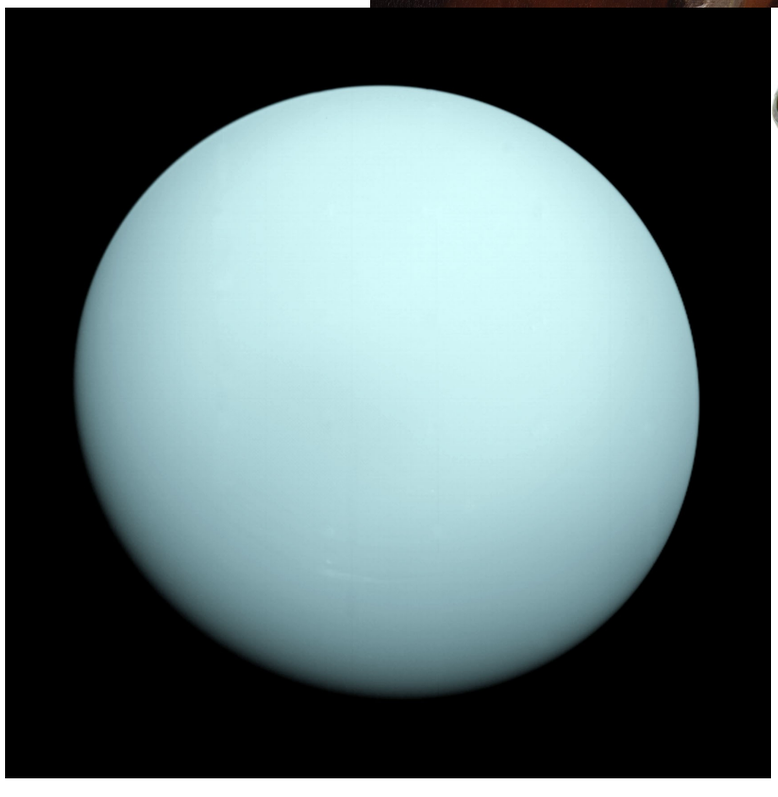
The story begins in...

Bath, Somerset

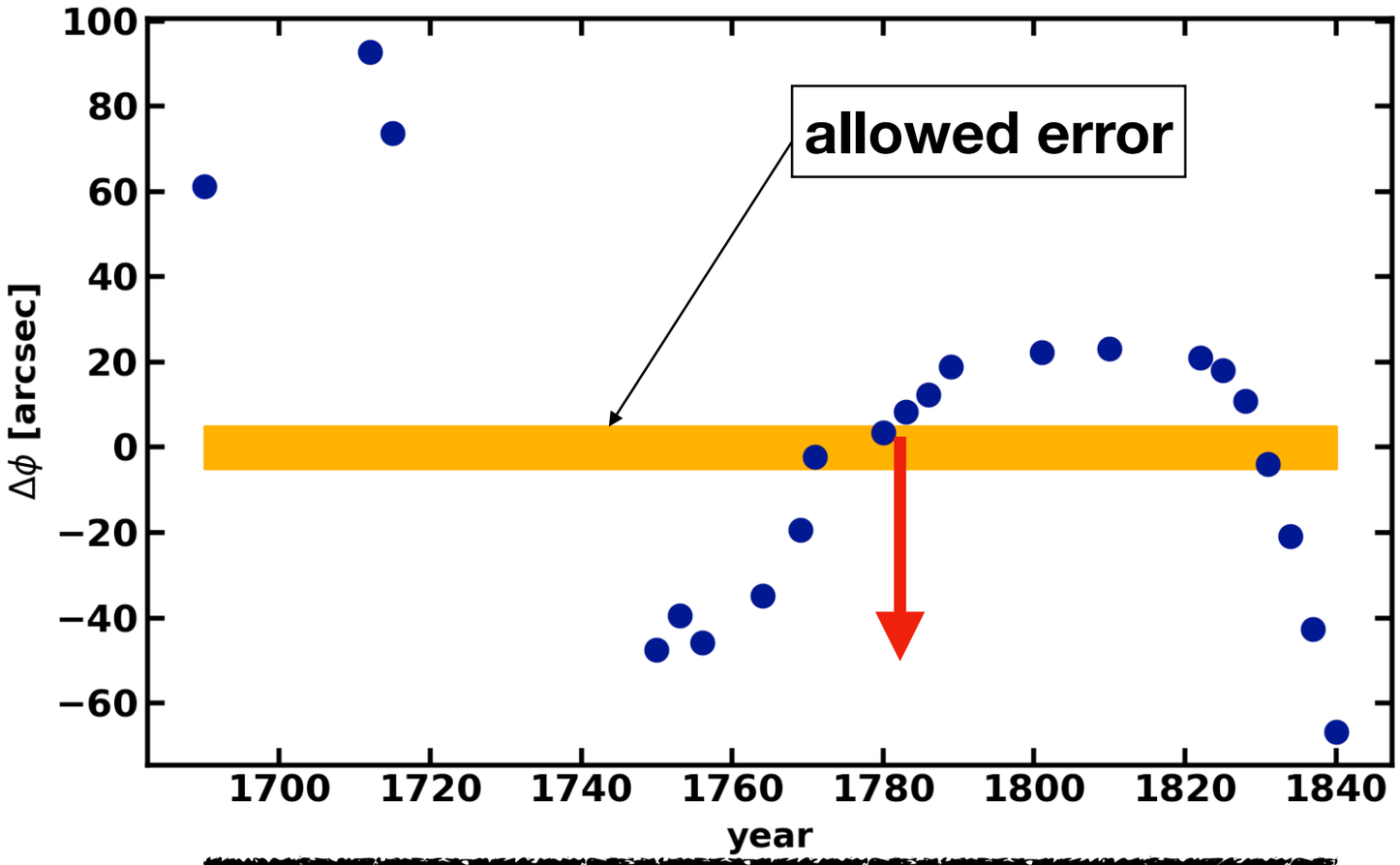
The story begins with Uranus

- **Friedrich Wilhelm Herschel** (1738 - 1822) or Frederick William Herschel
- **economic migrant** from Hanover, set to **teach music** in Bath
- in **free time** (with help of his sister Caroline) **makes telescopes**
- and **observes stars**
- looking for binary stars on **13 March 1781** discovered "**Georgium Sidus**" (George's Star or "The Georgian") aka: **Uranus**
- World is **astonished** and **excited**
  - "He broke through the barriers of the heavens"
  - the first new member of Solar system
  - doubled the size of the Solar system - Uranus was **very far**: 19.2 AU



The trouble with Uranus

- Uranus was **observed** 17 times **before the discovery** (Flamsteed, Lemonnier, Bradley, Mayer)
- Alexis Bouvard made "**Tables of Uranus**" (1821) - Uranus ephemeris
- it seemed **impossible to predict** where **Uranus will be**
  - very different from other planets, including Jupiter and Saturn
- a **major problem** in **astronomy** of the 1st half of the 19th century
- **by 1840s** it was generally **assumed** that this must be **due to** an **unseen (external) planet**



- allowed **uncertainty** to the determination of the position of Uranus was **<5" in 1820s**
- in 1826, it was typically measured to be ~10", but it was decreasing with time, only to start increasing

The usual story

- in **1841**, a young Cambridge math student **John Couch Adams**
  - "*Formed a design in the beginning of this week, of investigating, as soon as possible after taking my degree, the irregularities in the motion of Uranus...*" (diary 3 July 1841)
- in **1843**, Adams graduated, and during the summer started **working** on the "**problem of Uranus**" --> **initial solution** was **very promising**
  - back in Cambridge 1843-1844, Adams has lots of teaching duties, but also starts collaborating with **James Challis** (director of Cambridge Observatory)
    - got **more data** on Uranus from Royal Astronomer **George Biddel Airy**
    - forgets about the work, restarts, forgets**...**
- in **1845**: produces a **prediction** on the **location** of the possible planet, which he wants to **show to Airy**

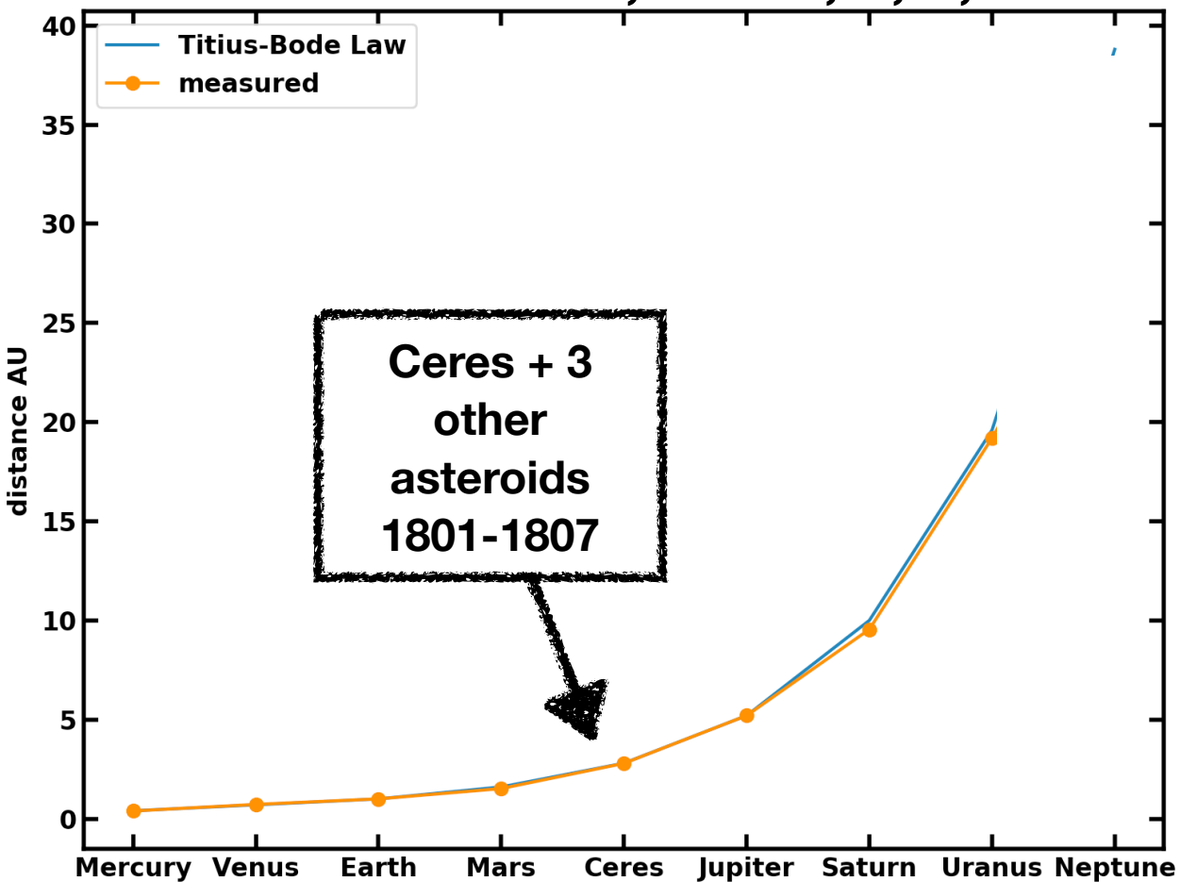
John Couch Adams (1819-1892)

Cambridge

- Adams assumed **distance** based on **Titius-Bode Law**
  - new planet is at ~**38 AU**
  - **elliptical orbit**
  - determines all elements of the orbit
    - **longitude of the planet: 325º 8'**
- **late September 1845** - 1st (unannounced) visit to Greenwich
  - Airy in France
- **late October** - 2nd (unannounced) visit to Greenwich
  - passes by **twice**, early in the morning and during the "dinner" time
  - Airy walking or eating: **butler sends Adams away**
  - **Hyp I** (drafted in front of an angry butler)
- **November 1845**:
  - **Airy** is **interested** and **asks** a question about the "radius vector" of Uranus
  - Adams **doesn't reply**
- **teaching** and **work on** some **comets** with Challis

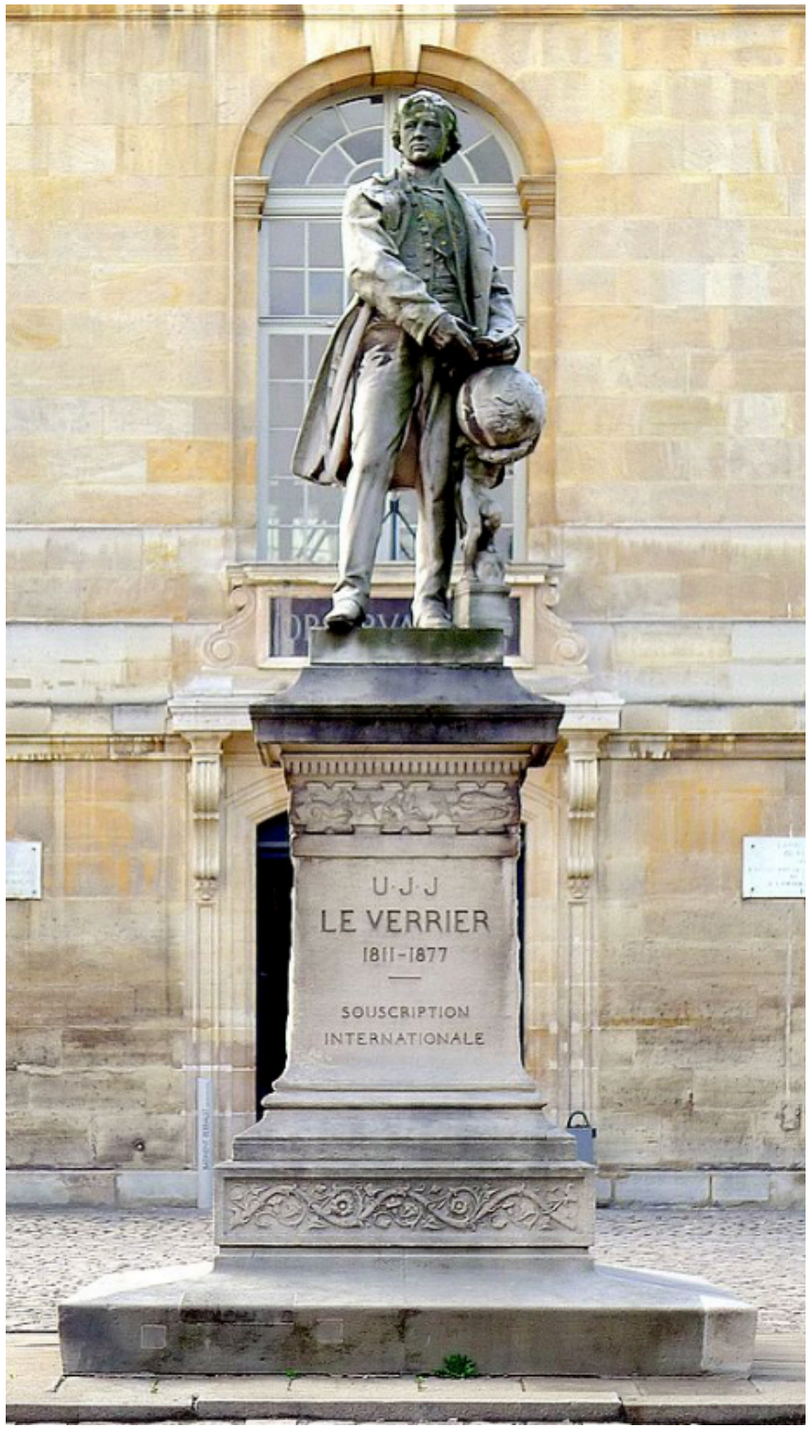
Titius-Bode law:
each planet is approximately 2 times more distant

$a=0.4+0.3\times2^m$, $m=-\infty, 0, 1, 2$



Paris

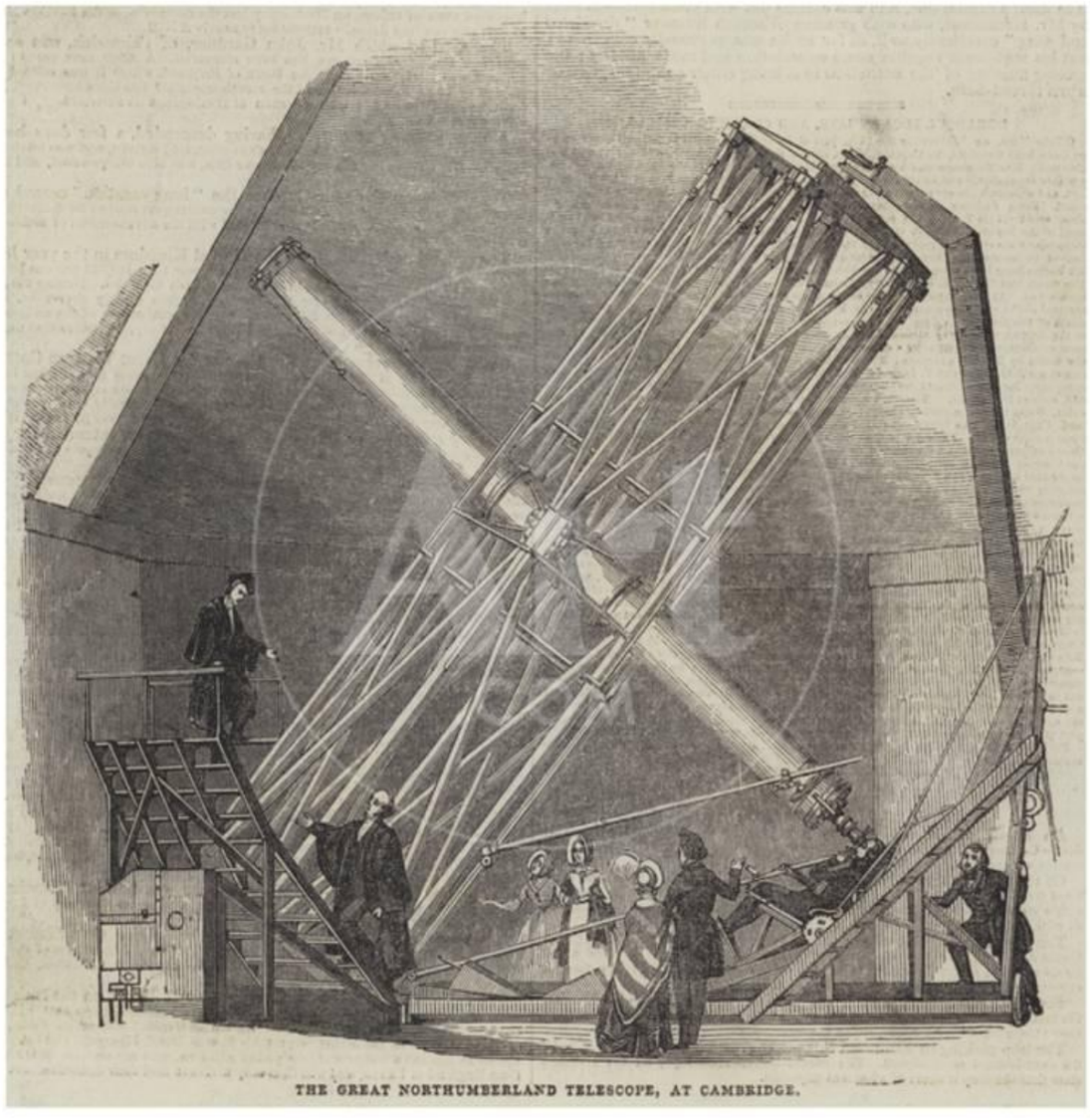
- 1839 **Jean Joseph Urbain Le Verrier** accepts an astronomy teaching position on École Polytechnique and changes carrier
  - works on **orbits of comets** and **planets** (especially Mercury)
  - **François Arago** (1786 - 1853) decides that **Le Verrier** should **continue working** on the **problem of Uranus** instead of Bouvard(s)
- **10 November 1845** - **1st Memoir on Uranus** to Paris Academy
  - analysis of all previous observations (Bouvard's Tables) with a conclusion: **known bodies of the Solar System are not enough to explain motion of Uranus**
- **1 June 1846** - **2nd Memoir on Uranus** to Paris Academy
  - 1st prediction on the **location of the new planet** (longitude=325 deg) with a "large" error (10 degrees)
- **31 August 1846** - **3rd Memoir on Uranus** to Paris Academy
  - final prediction, **longitude: 326º 32'** (for 1 Jan 1847)
  - "**it should be seen as a disk of 3 arcsec in diameter**"



Jean Joseph Urbain Le Verrier (1811-1876)

France 1 - England 0

- **June 1846**: Airy reads the 2nd Memoir of **Le Verrier** and his prediction
  - it **agrees** pretty **well** with Adams' solution of October 1845
  - Airy tells Challis to start a **search for the planet** using the Northumberland Telescope
- **summer 1846**: Challis starts the **"secret" Cambridge search**
  - Adams provides **ephemeris** (using his **Le Verrier's** initial orbit)
  - Challis **observes** "the new planet" on August 4 and 12, but **doesn't check** the data....
- **August 1846 - Hyp II -** final (pre-discovery) model by Adams
- **23 September 1846**: **Neptune** is **discovered** in Berlin
- **30 September 1846** Challis and Adams hear about the discovery

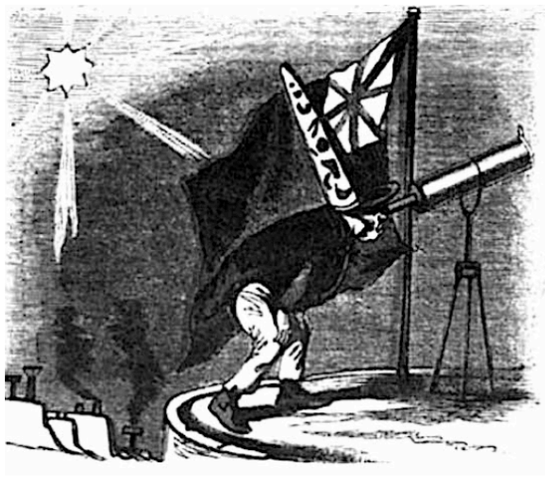


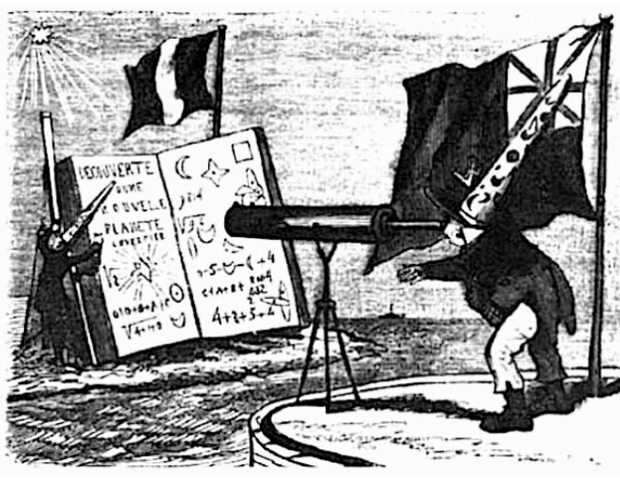
Northumberland Telescope, Cambridge Observatory

Post discovery

- **3 October 1846** (The Athenaeum):
  - John Herschel **announces** that **Adams** also **predicted** the **location**
- **17 October 1846** (The Athenaeum):
  - Challis and Adams presents the **orbit** of the **new planet** based on the observations in **Cambridge** (August) and **Berlin** (September)
  - Challis and Adams propose a name **"Oceanus"**
- French are "annoyed" and accuse the British for a "**Planetary Theft**"
- **19 October 1846** (Academy of Sciences):
  - François Arago declares the name of the planet is "**Le Verrier**"
- **November**: Adams for the 1st time publicly presents (published) his theory in MNRAS (and in Nautical Almanac for 1851 (1847))

French Newspapers caricatures about the discovery of the new planet

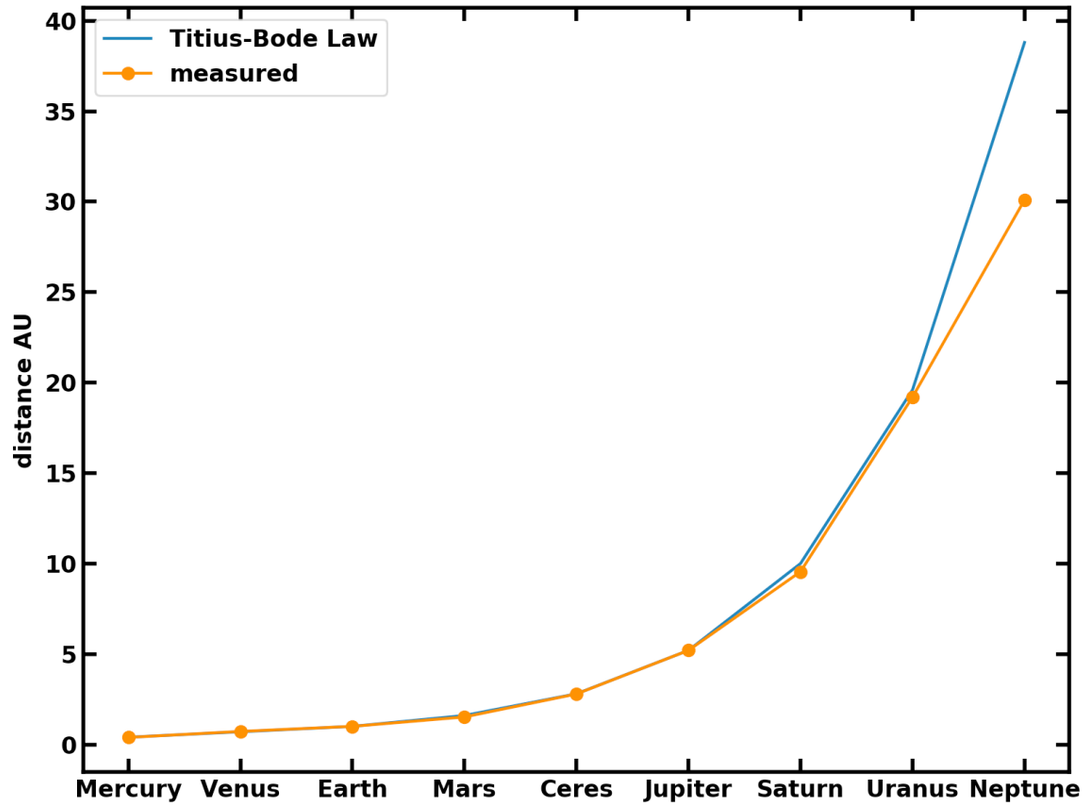




"Gott gebe, das nicht bald eine politische Kriegserklärung zwischen England und Frankreich folge." Schumacher to Gauss, 20.11.1846

The new orbit

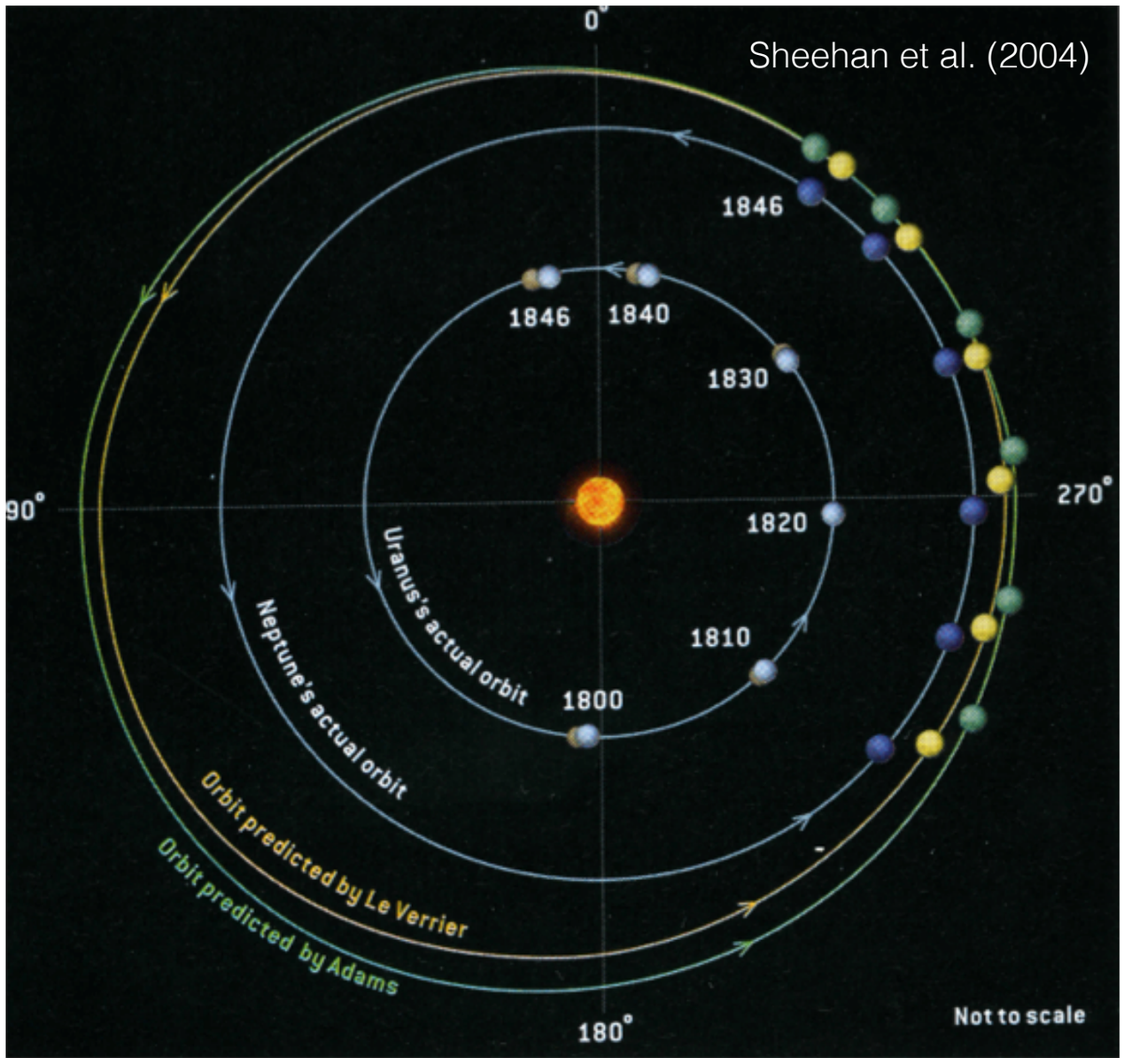
- Titius - Bode law is "broken"
- **Sears Cook Walker** (1805-1853) at US Naval Observatory **determines** the most **accurate orbit**
  - found that Michel La Lalande **observed** Neptune on **10. May 1795** (important point on the orbit)
- **Almost all elements of the orbits were wrongly estimated**



orbit	Adams	Le Verrier	Walker	Neptune
semi-major axis	37,25	36,15	30,25	30,33
eccentricity	0,12062	0,10761	0,00884	0,009456
orbital period	227,3	217,4	166,4	164,8
mass [Msun]	0,00015	0,00011	0,000067	0,0000515
Longitude, 01.01.1847	329° 57’	326° 32’	328° 7’ 34’’	

The new orbit

1. How did they find the planet?
2. Fluke of orbital timing?
3. Did they actually found the planet they were looking for? (as US mathematician Benjamin Pierce asked in 1847)



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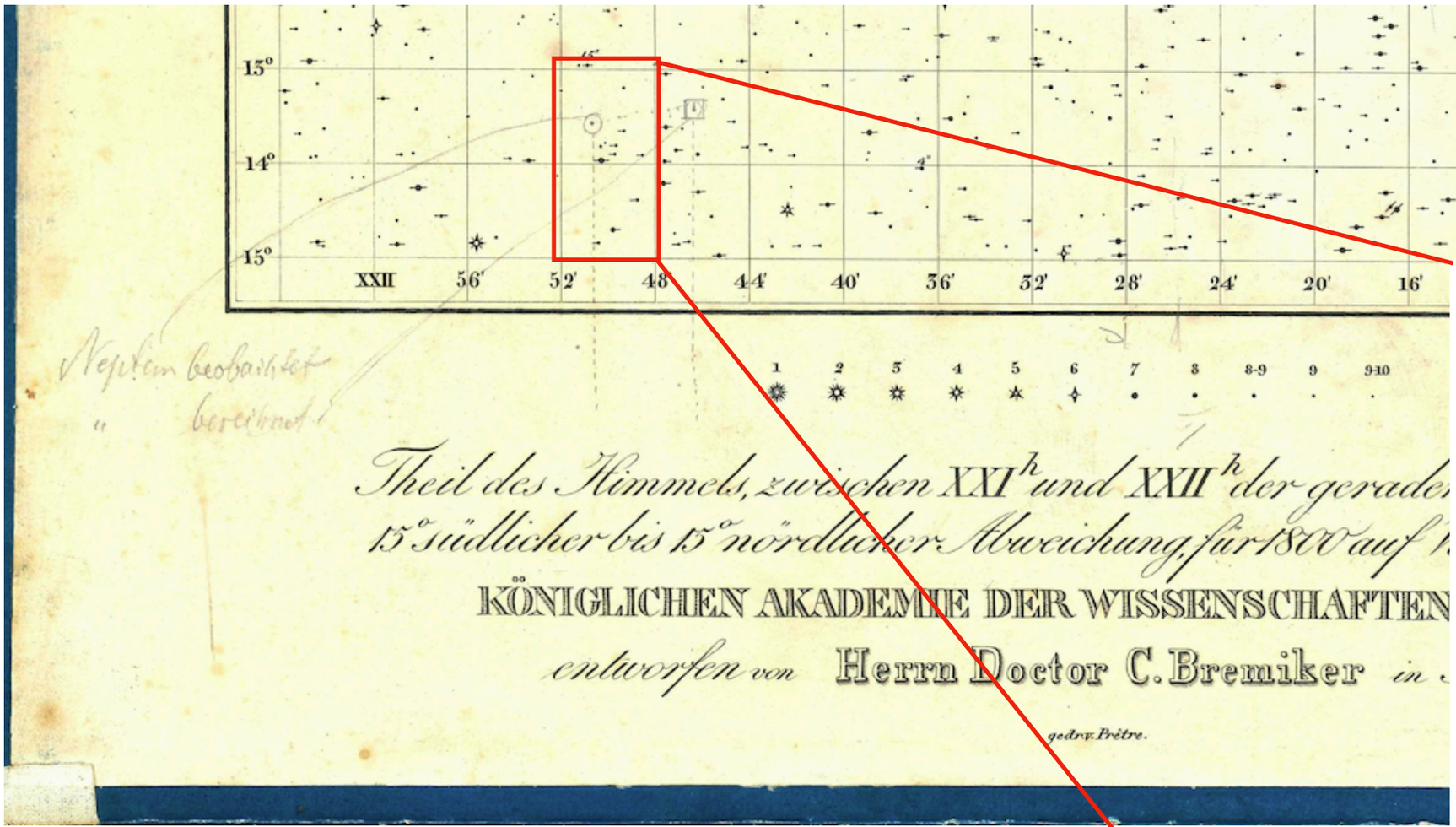
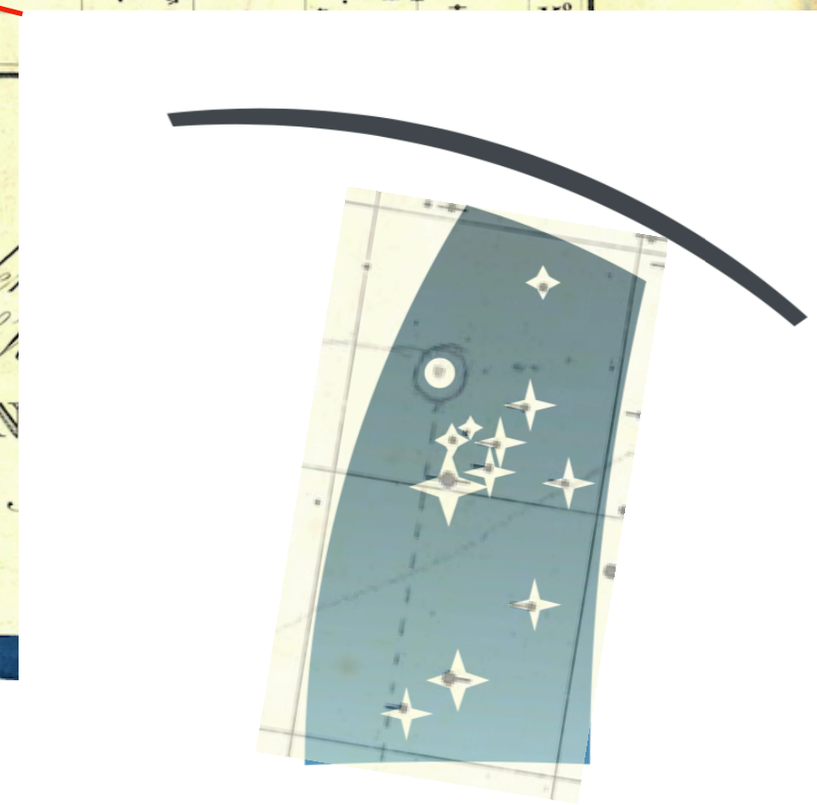
Within "1 degree"





- Pure **coincidence** that the prediction was so close (~1 degree)
- **Both** prediction were **astounding** and **wrong**
- **no** real **estimates** of the **uncertainties** (see Gapaillard 2015, JHA, 46, 48)

AIP

"Lucky" Math

A modern view

- coupled harmonic oscillators driven by external forces (Neptune's pull)

$$\ddot{u} - 2\Omega_1\dot{v} - 3\Omega_1^2 u = \epsilon F_r$$
$$\ddot{v} + 2\Omega_1\dot{u} = \epsilon F_\phi$$

$$\epsilon = \frac{Gm_2}{R_2^2}$$

- degeneracy with respect to mass and distance of Neptune

$$F_r = \frac{\cos\Omega\tau}{(1 - 2k\cos\Omega\tau + k^2)^{2/3}} - \cos\Omega\tau$$

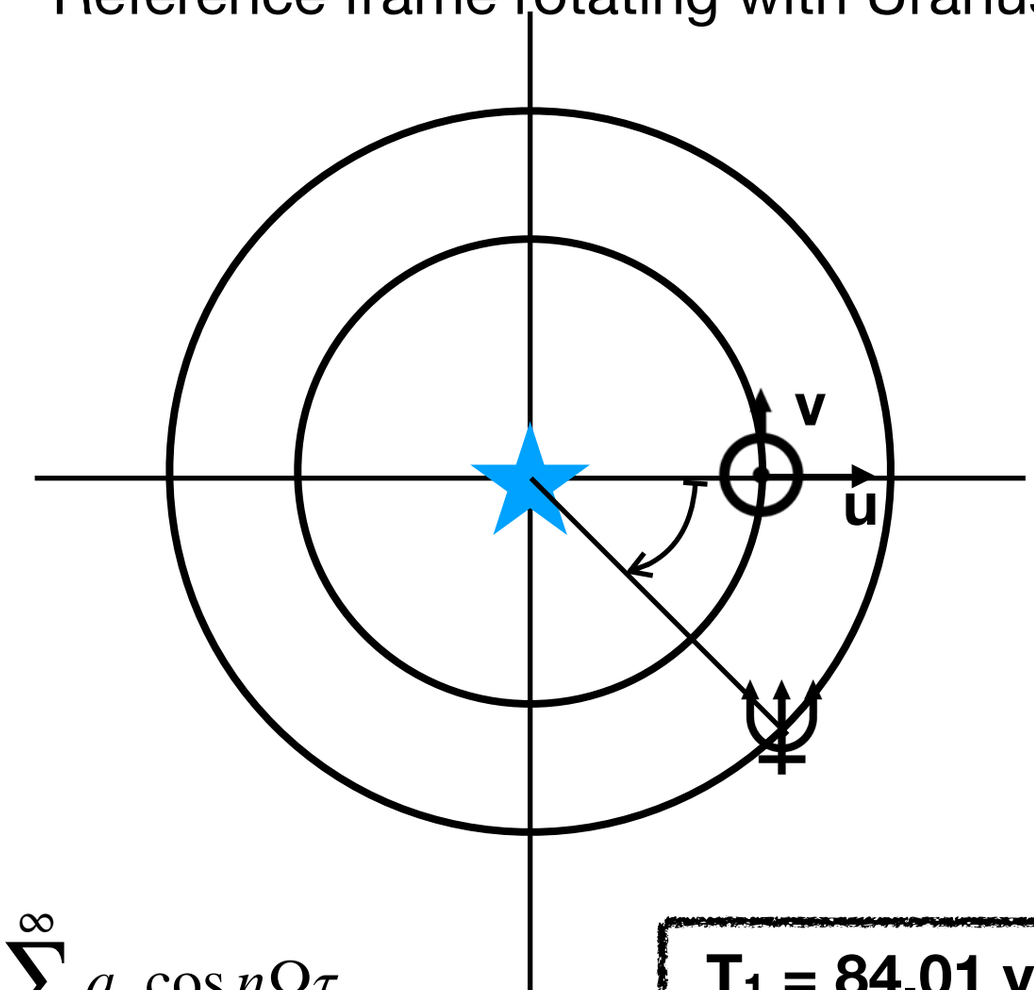
$$F_\phi = \frac{-\sin\Omega\tau}{(1 - 2k\cos\Omega\tau + k^2)^{3/2}} + \sin\Omega\tau$$

$$\tau = t_1 - t_0 \qquad k = \frac{R_1}{R_2}$$

$$\Omega_i = 2\pi/T_i \qquad \Omega = \Omega_1 - \Omega_2$$

Lai, Lam & Young (1990, AmJph, 58, 946)

Reference frame rotating with Uranus



$$F_r = \sum_{i=1}^{\infty} a_n \cos n\Omega\tau$$

$$F_\phi = \sum_{i=1}^{\infty} b_n \sin n\Omega\tau$$

T_1 = 84.01 yr
T_2 = 164.8 yr
t_0 = 1822

$$\Omega_1 \approx 2 \times \Omega_2$$
$$\Omega_1 \approx 2 \times \Omega$$

Is Neptune perturbing?

$$u = \epsilon \sum_n u_n \cos n\Omega\tau$$

$$v = \epsilon \sum_n v_n \sin n\Omega\tau$$

$$u_n = \frac{n\Omega a_n - 2\Omega_1 b_n}{n\Omega(\Omega_1^2 - n^2\Omega^2)}$$

$$v_n = \frac{-2n\Omega\Omega_1 a_n + (3\Omega^2 + n^2\Omega^2) b_n)}{n^2\Omega^2(\Omega_1^2 - n^2\Omega^2)}$$

$$\Omega = \Omega_1 - \Omega_2 \qquad \Omega_1 \approx 2 \times \Omega_2$$

T_1 = 84.01 yr
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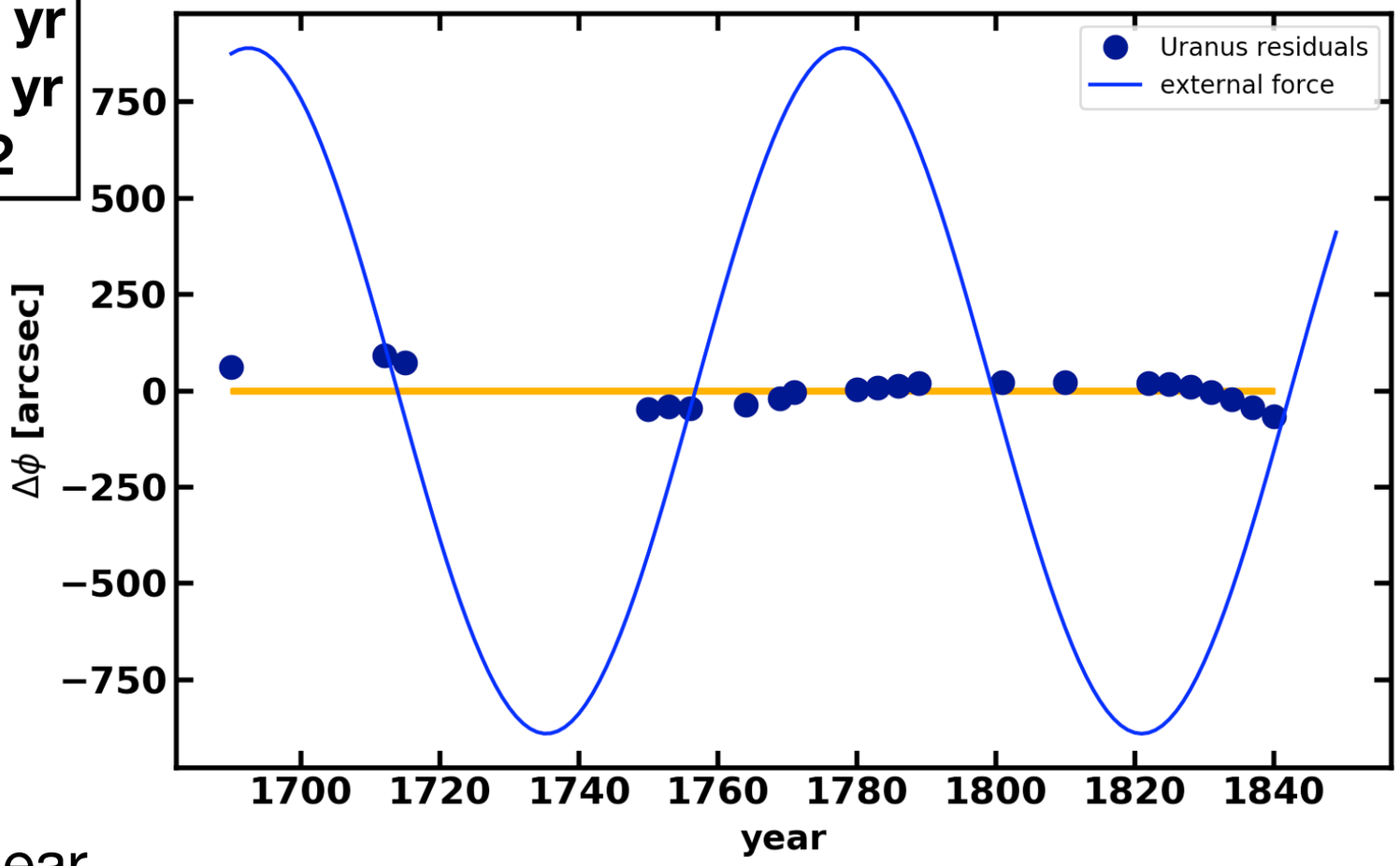
t_0 = 1822



- Uranus and Neptune are in near 1:2 resonance
- external force has nΩ driving frequencies
- dominant terms are n=2

Contrary to historical assumptions:
residuals in Uranus' motion cannot be directly associated to perturbations due to Neptune

Complete solution

- Need to combine all effects (natural and driving frequencies) of the system

$$\Delta\phi(\tau) = -\gamma \sin 2\Omega\tau + \beta_1\Omega_1\tau + \beta_2 + \beta_3 \sin \Omega_1\tau + \beta_4 \cos \Omega_1\tau$$

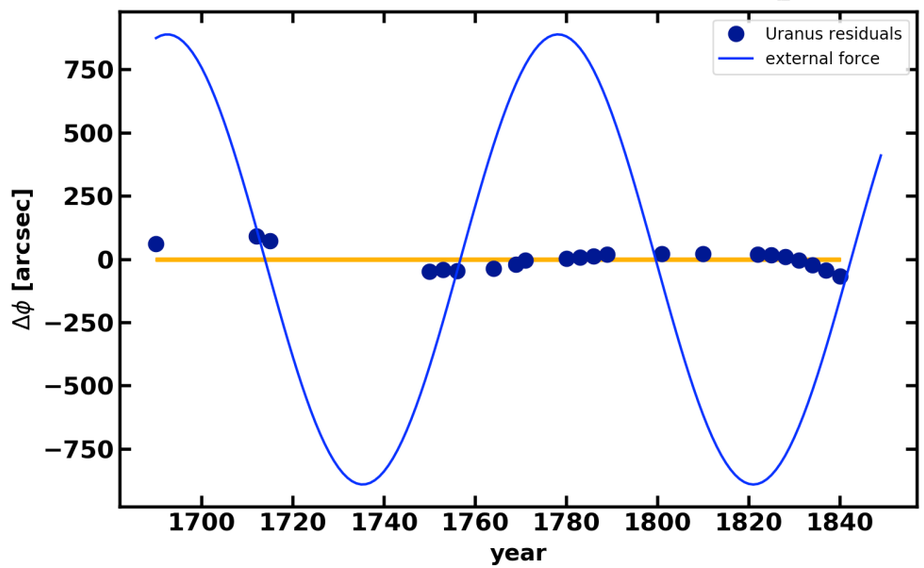
- natural frequencies, driving frequencies and the near resonances
- natural frequency Ω_1=0.07479
- dominant driving term frequency 2Ω=0.07331

driving force: Neptune's direct influence

coupled harmonic oscillator: orbit with a semi-major axis $a_0+\delta a$ (these terms are small)

coupled harmonic oscillator: orbit with a semi-major axis $\varepsilon_0+\delta\varepsilon$
$\Omega_1 \approx 2\Omega$
$\beta^2_3 + \beta^2_4 \approx \gamma^2$ and $\delta\varepsilon = -\gamma/2$

Perturbed orbit of Uranus resembles an unperturbed orbit with a slightly different eccentricity



"Measured" deviations are small as the orbit of Uranus has wrong eccentricity

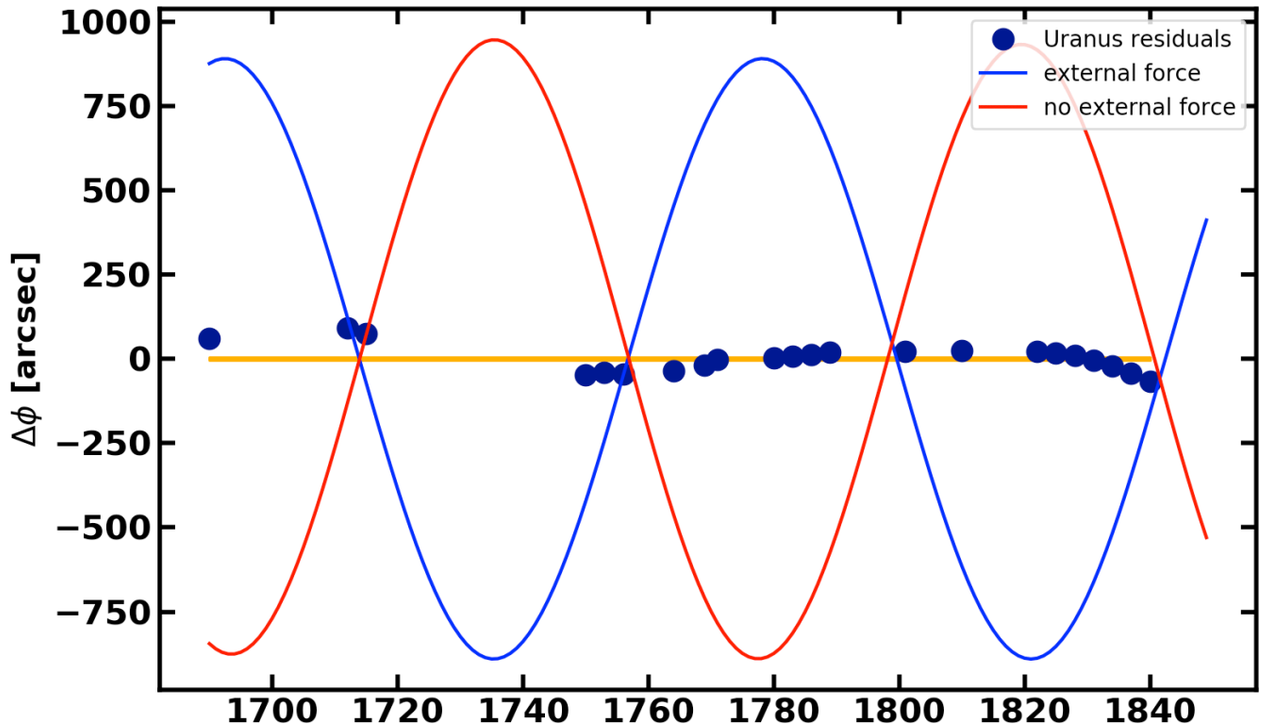
Complete solution

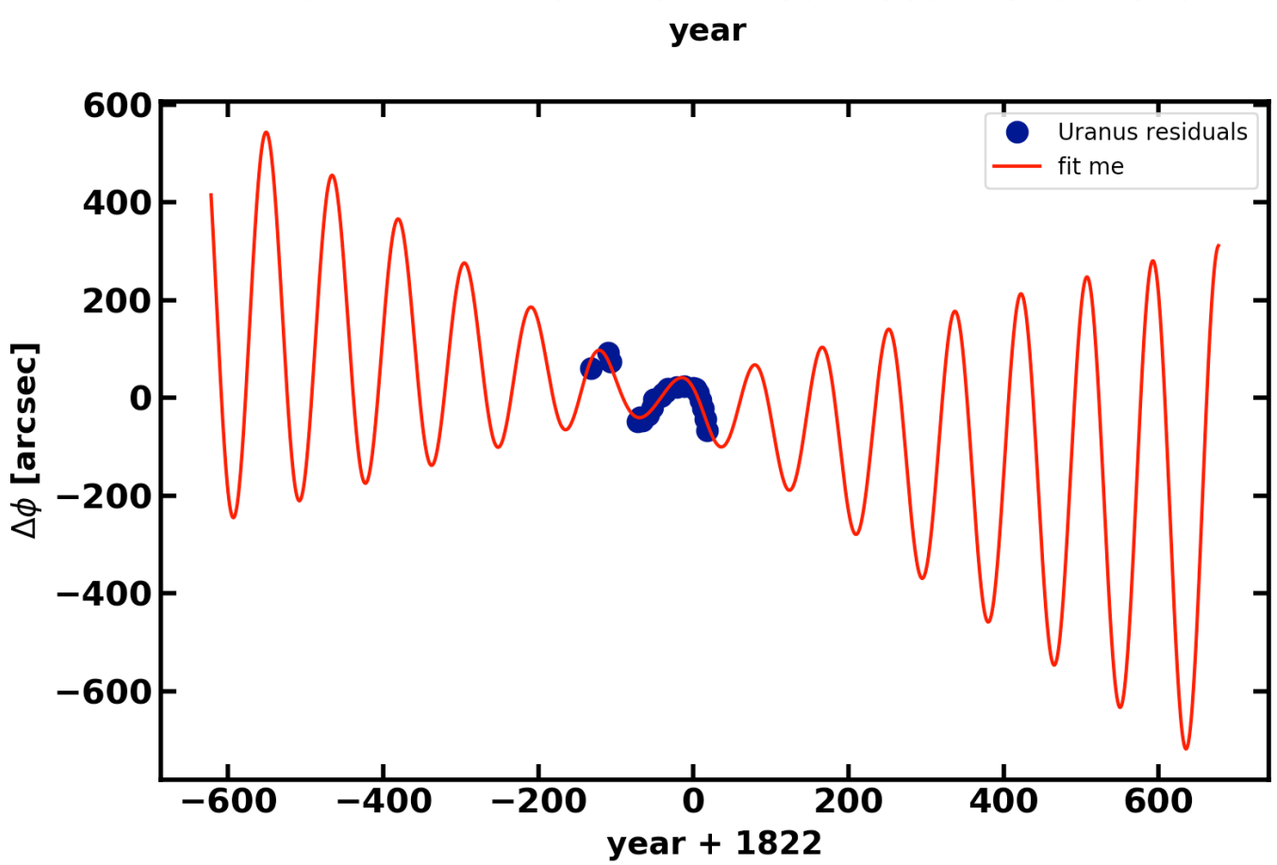
- Need to combine all effects (natural and driving frequencies) of the system

$$\Delta\phi(\tau) = -\gamma \sin 2\Omega\tau + \beta_1\Omega_1\tau + \beta_2 + \beta_3 \sin \Omega_1\tau + \beta_4 \cos \Omega_1\tau$$

- natural frequencies, driving frequencies and the near resonances

- natural frequency Ω_1=0.07479
- dominant driving term frequency 2Ω=0.07331
- natural frequency and dominat driving frequency are very similar, but $2\Omega \lesssim \Omega_1$
- beat frequency $\Omega_b = \Omega_1 - 2\Omega$ = 0.00147 or T_b = 4273 years

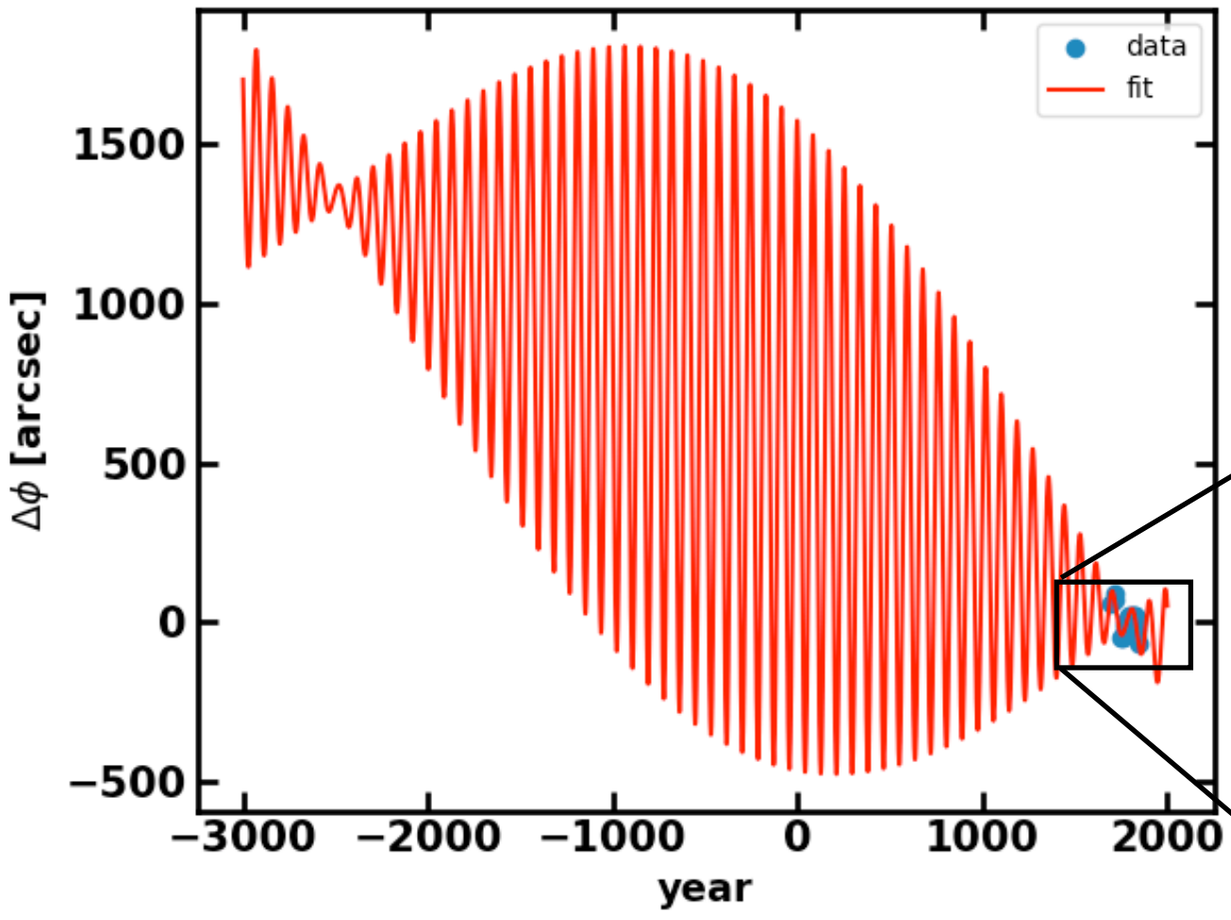




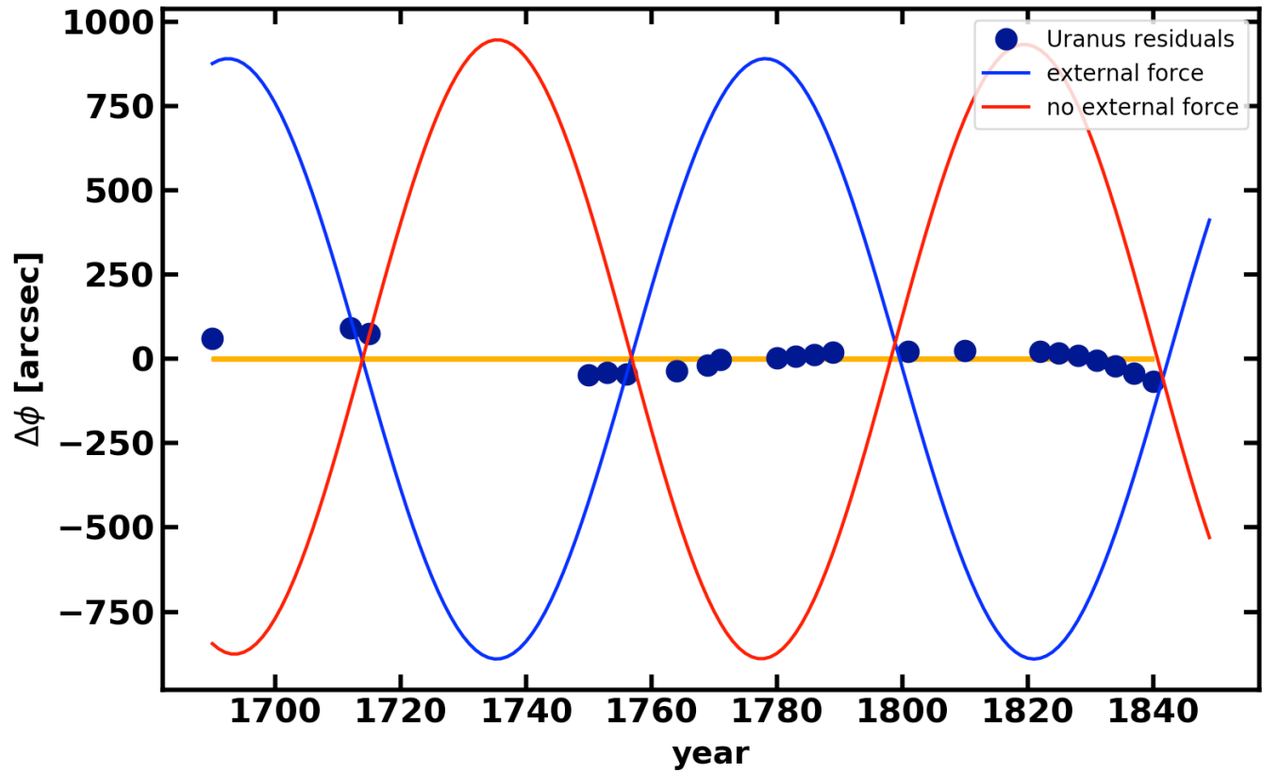
Complete solution

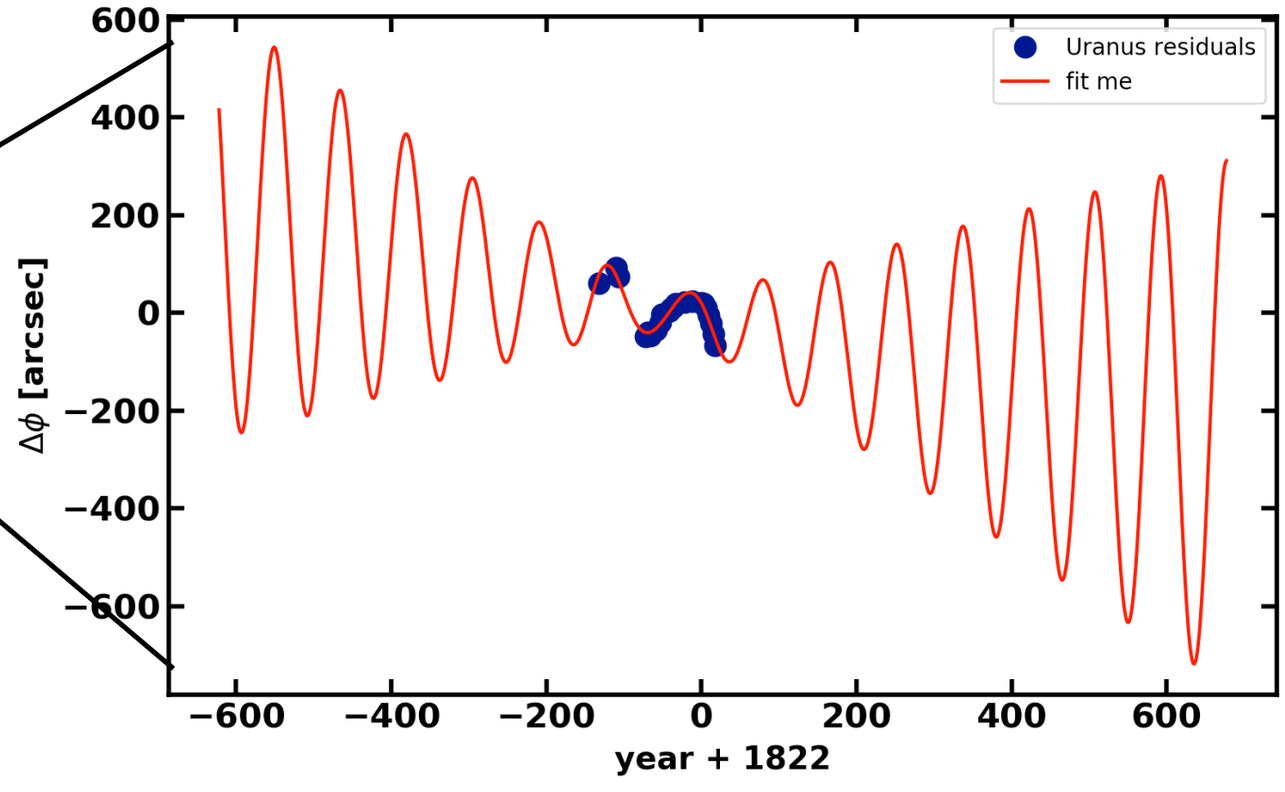
- Need to combine all effects (natural and driving frequencies) of the system

$$\Delta\phi(\tau) = -\gamma \sin 2\Omega\tau + \beta_1\Omega_1\tau + \beta_2$$



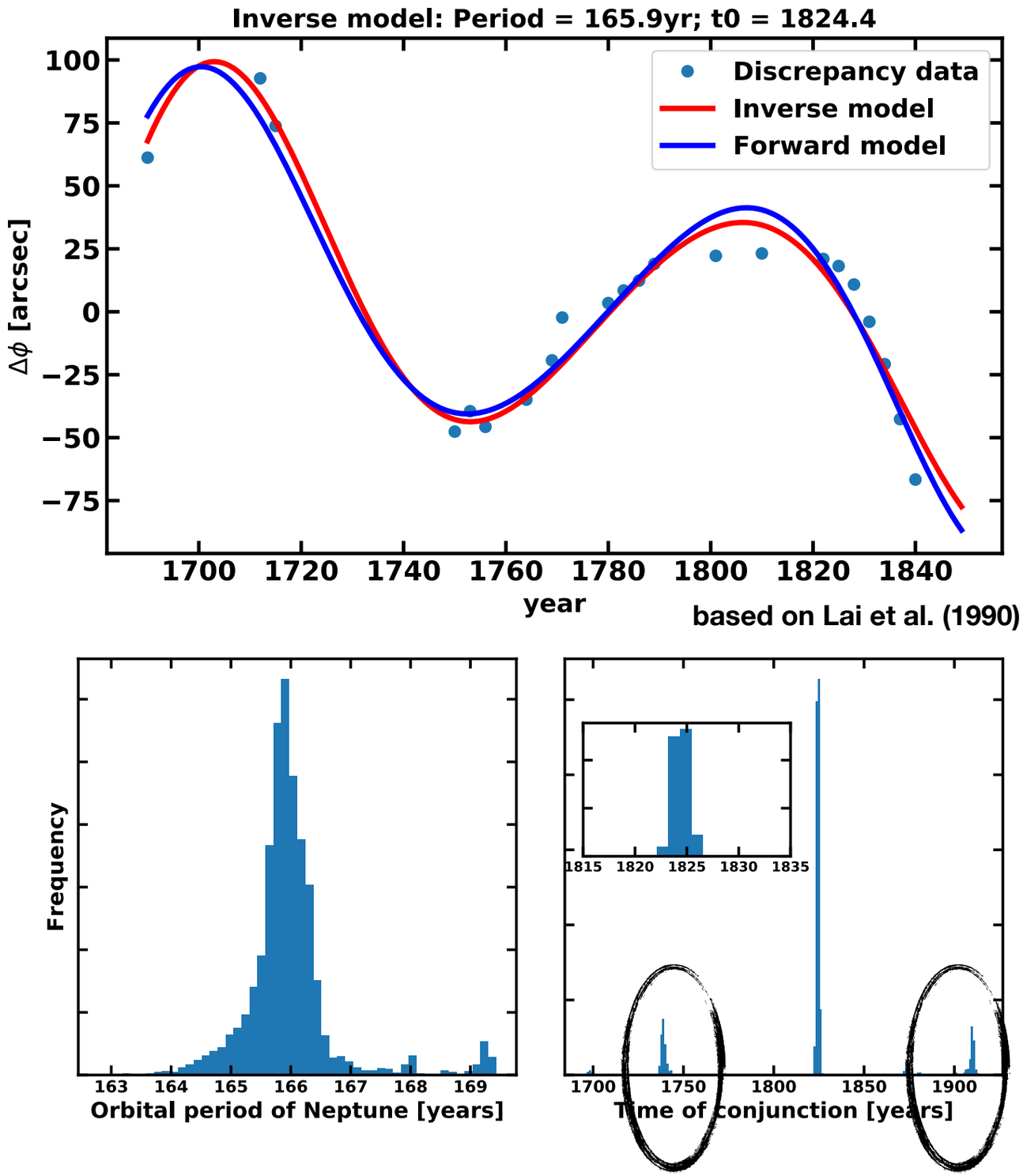
0.00147 or $T_b = 4273$ years





The inverse problem

- Bayesian fit to the historic data (10^6 models in a few seconds)
- best fit values
  - T_{orbit} = 166 yr (165yr)
  - t_0 = 1824 (1822)
  - "wrong" as it can be shown that inverse problem provides a solution with $2\Omega > \Omega_1$
- not all parameters are well determined
  - e.g. γ and β_3 (due to near-resonance) can only be determined together (40% of models don't give "correct" values for γ and β_3)
  - t_0 as a test case:
    - 25% of models provide t0+T/2 or t0-T/2
    - there was a substantial chance that the solution would have the same orbit, but the phase off by T/2
- what a luck to have Neptune and Uranus in conjunction



"Lucky" choice of observers/observatory

The abuse of Airy

- **Sir George Biddle Airy** (1801 -1892)
  - Lucasian Professor of Mathematics (1826 - 1828)
  - Plumian Professor of Mathematics and Experimental Philosophy and Director of Cambridge Observatory (1828 - 1835)
  - Royal Astronomer and Director of Greenwich Observatory (1835 - 1881)
- Works on **mathematics**, **physics, astronomy**
  - Airy function, Airy disk, stress function method, diffraction theory, observations of Venus, Uranus, Moon, mean density of Earth, Airy (reference) Geoid
  - as Royal Astronomer work on many committees (e.g. gauge of the railway tracks in Britain....)
- a **central character** in the story

> … As I have said (1845) I obtained no answer from Adams to a letter of enquiry. Beginning with June 26th of 1846 I had correspondence of a satisfactory character with Le Verrier, who had taken up the subject of the disturbance of Uranus, and arrived at conclusions not very different from those of Adams. I wrote from Ely on July 9th to Challis, begging him, as in possession of the largest telescope in England, to sweep for the planet, and suggesting a plan. I received information of its recognition by Galle, when I was visiting Hansen at Gotha. For further official history, see my communications to the Royal Astronomical Society, and for private history see the papers of the Royal Observatory. **I was abused most savagely both by the English and French.** (Airy, 1896:181)

Why is Airy not mentioning Germans?

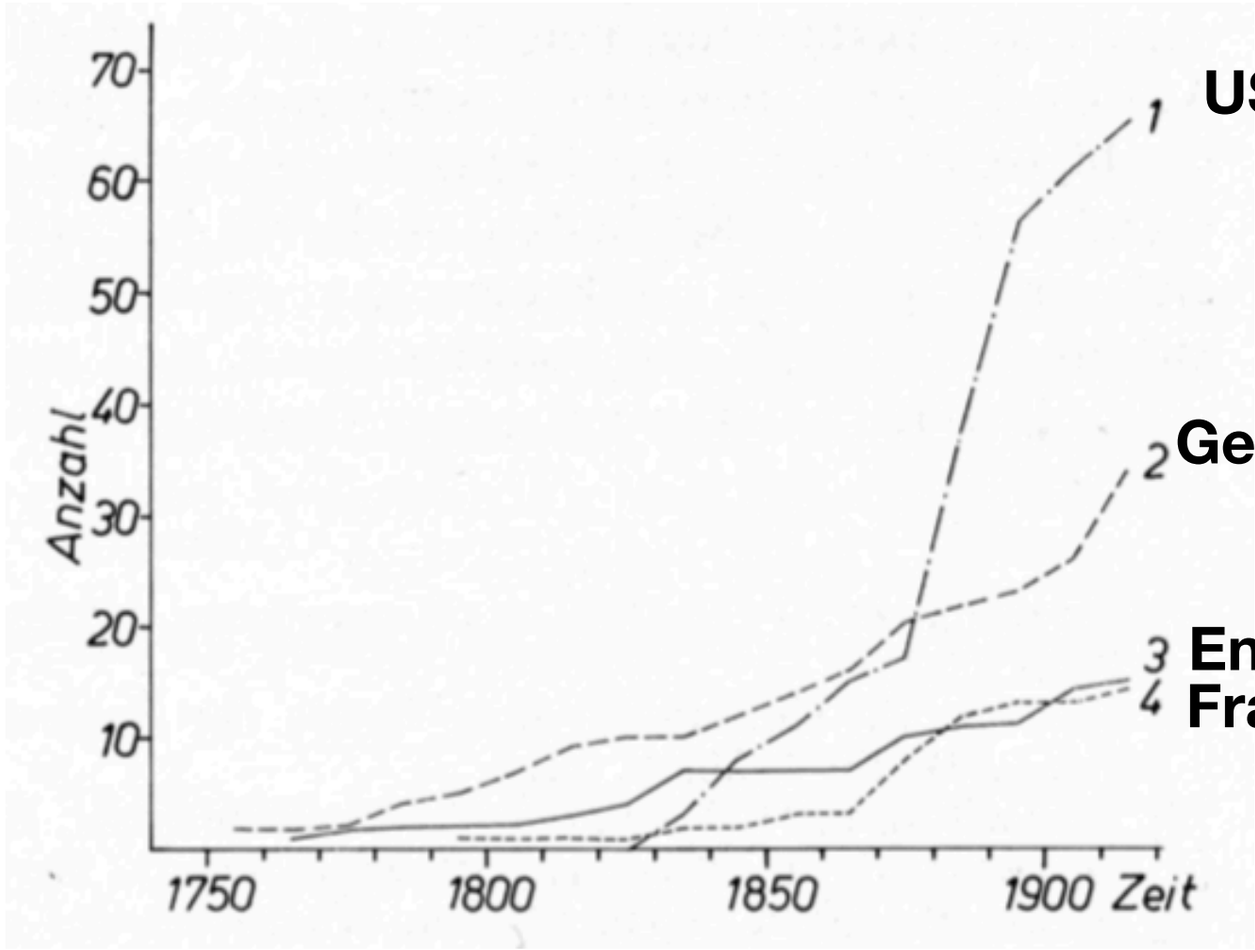
- Airy has **extensive links** with **German astronomers** ("visiting Hansen in Gotha", later at Schumacher's in Altona)
- **Heinrich Christian Schumacher** (1780-1850)
  - publisher of Astronomische Nachrichten (in Altona)
  - in correspondence with all astronomers in Europe
- but, in 1846 there is no "Germany"
- the **political divisions** among Germans actually was "**beneficial**"

Schumacher

German countries have most observatories

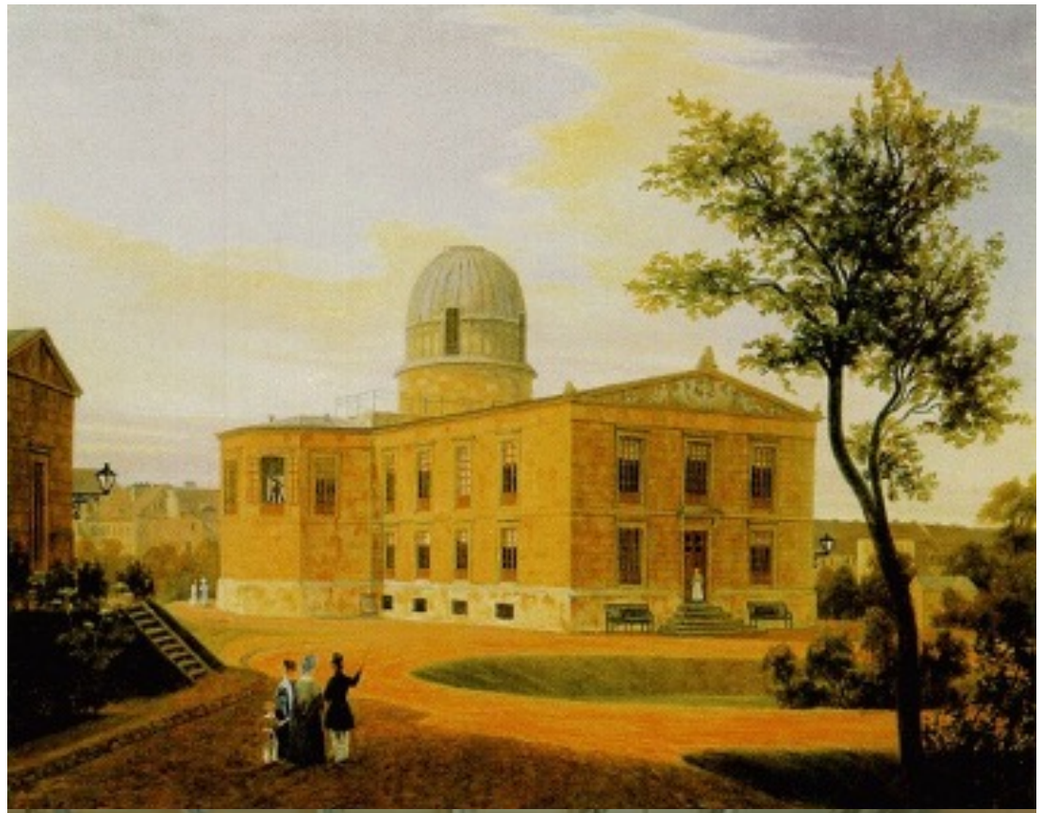
- "The progress of a people on its career of civilisation can be gauged by the number of observatories on its soil." **John Quincy Adam**s (6th President)
- **German countries** have **most observatories** until ~1870s
- in 1850 **more than England** and **France combined**!
- one could even say, it **is not surprising** that **Neptune was found in Germany** (by German astronomers)

Herrmann, 1973, Die Sterne, 49, 48



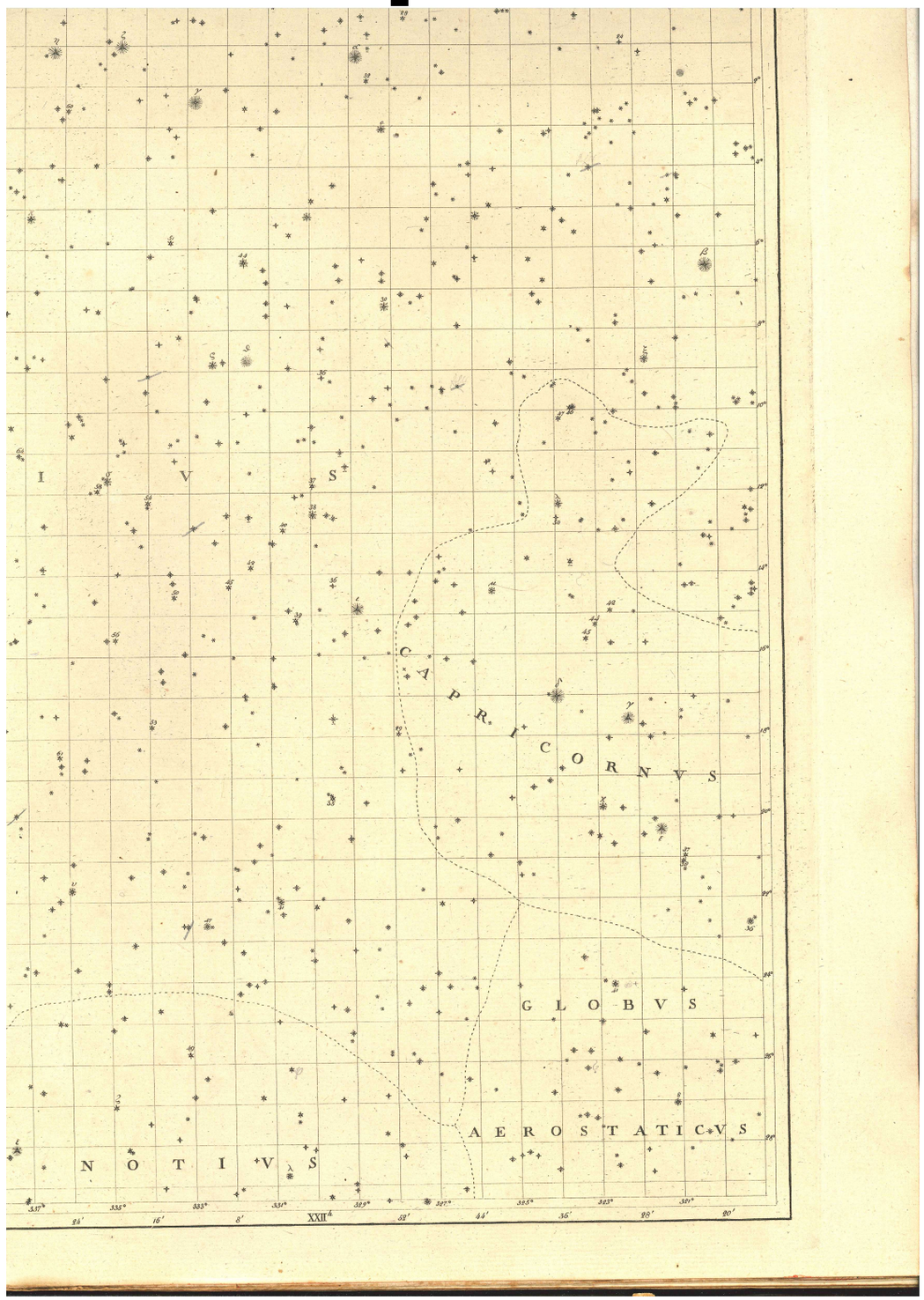
The facts

- Neptune was **discovered at Berlin Observatory** on 23. September 1846 by:
  - **Johann Gottfried Galle** (1812-1910)
  - **Heinrich Louis d'Arrest** (1822 - 1875)
- based on the theoretical prediction by **Urbain Jean Joseph Le Verrier** (1811 - 1877)
- Galle and d'Arrest used
  - a **Fraunhofer telescope** (24cm lens and 432cm focal lenght)
  - a **map Hora XXI**, of the Royal Berlin Academy of Sciences, produced by **Carl Bremiker**



How did they find Neptune

- **Galle** got the **letter** from **Le Verrier**
- **Galle asks** the **director Encke**, if he **could use** the **telescope** to look for the planet
- **Encke** has **55th birthday** and allows the **free use of the telescope**
- **d'Arrest overhears** the conversation and **asks if he can join Galle**
- **Galle accepts** him and tells him to **prepare the observations** (e.g. find the place on the sky from Le Verrier's orbital elements)
- **Galle and d'Arrest** enter to dome with the **standard sky chart of Harding**



Atlas novus Coelestis (Harding 1822)

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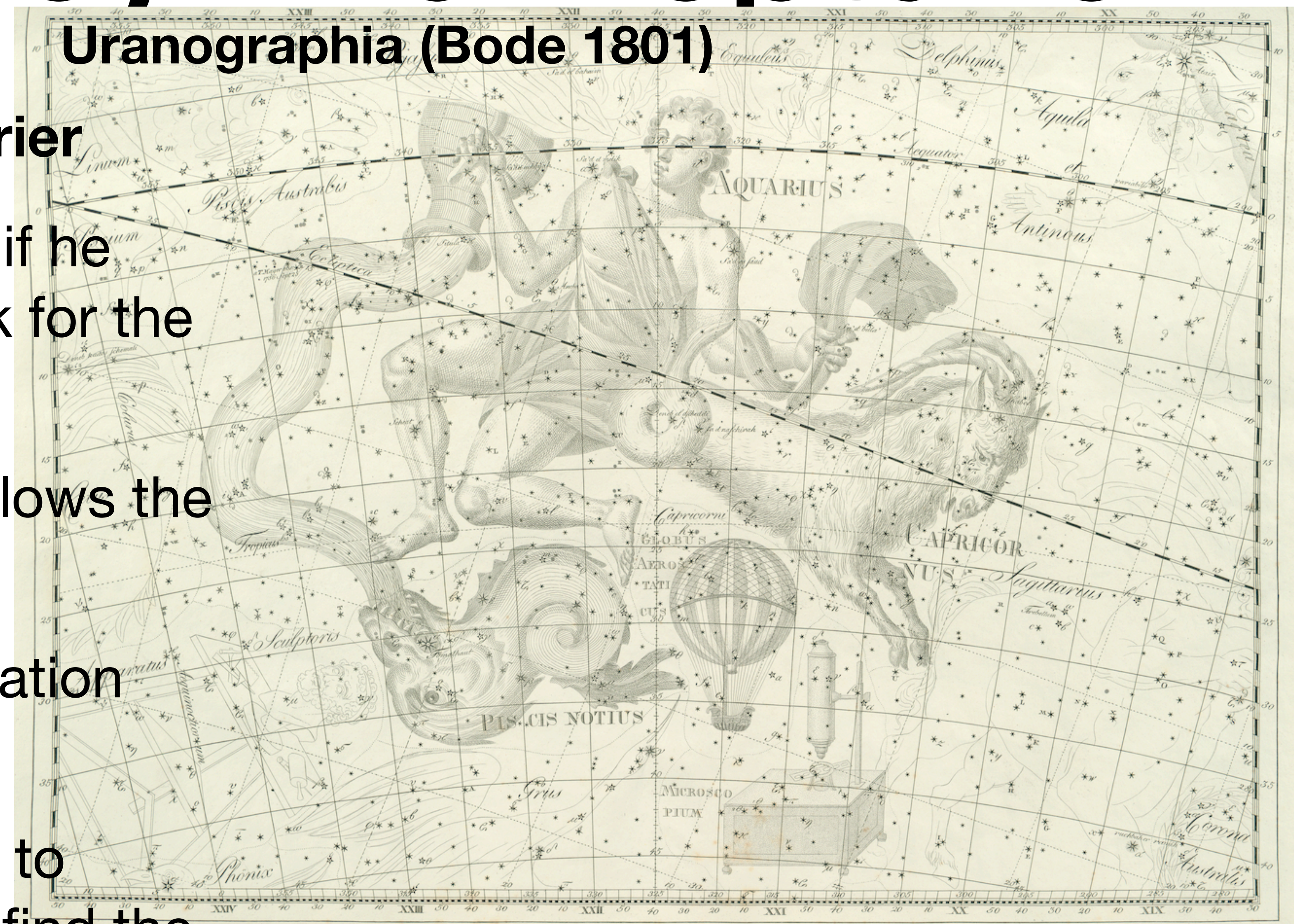
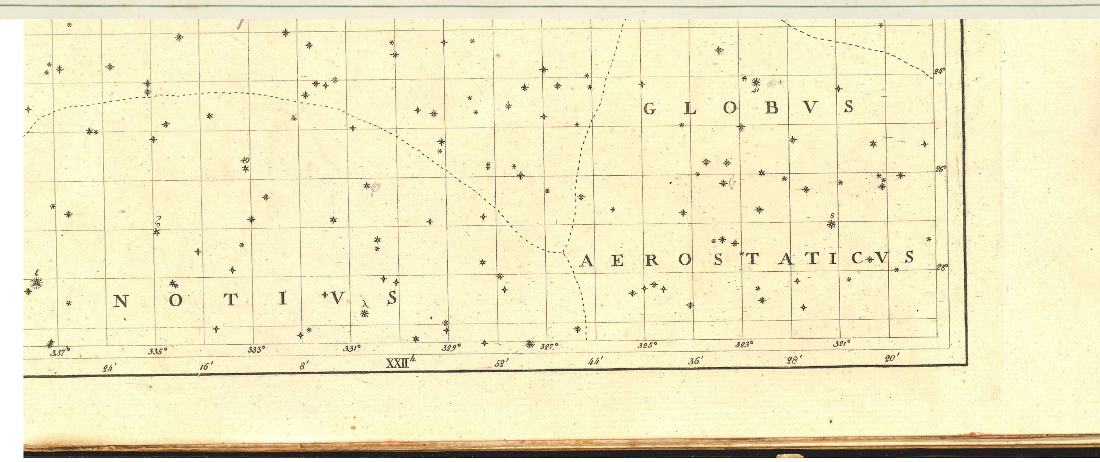
- **Encke** has **55th birthday** and allows the **free use of the telescope**
- **d'Arrest overhears** the conversation and **asks if he can join Galle**
- **Galle accepts** him and tells him to **prepare the observations** (e.g. find the place on the sky from Le Verrier's orbital elements)
- **Galle and d'Arrest** enter to dome with the **standard sky chart of Harding**

Uranographia (Bode 1801)

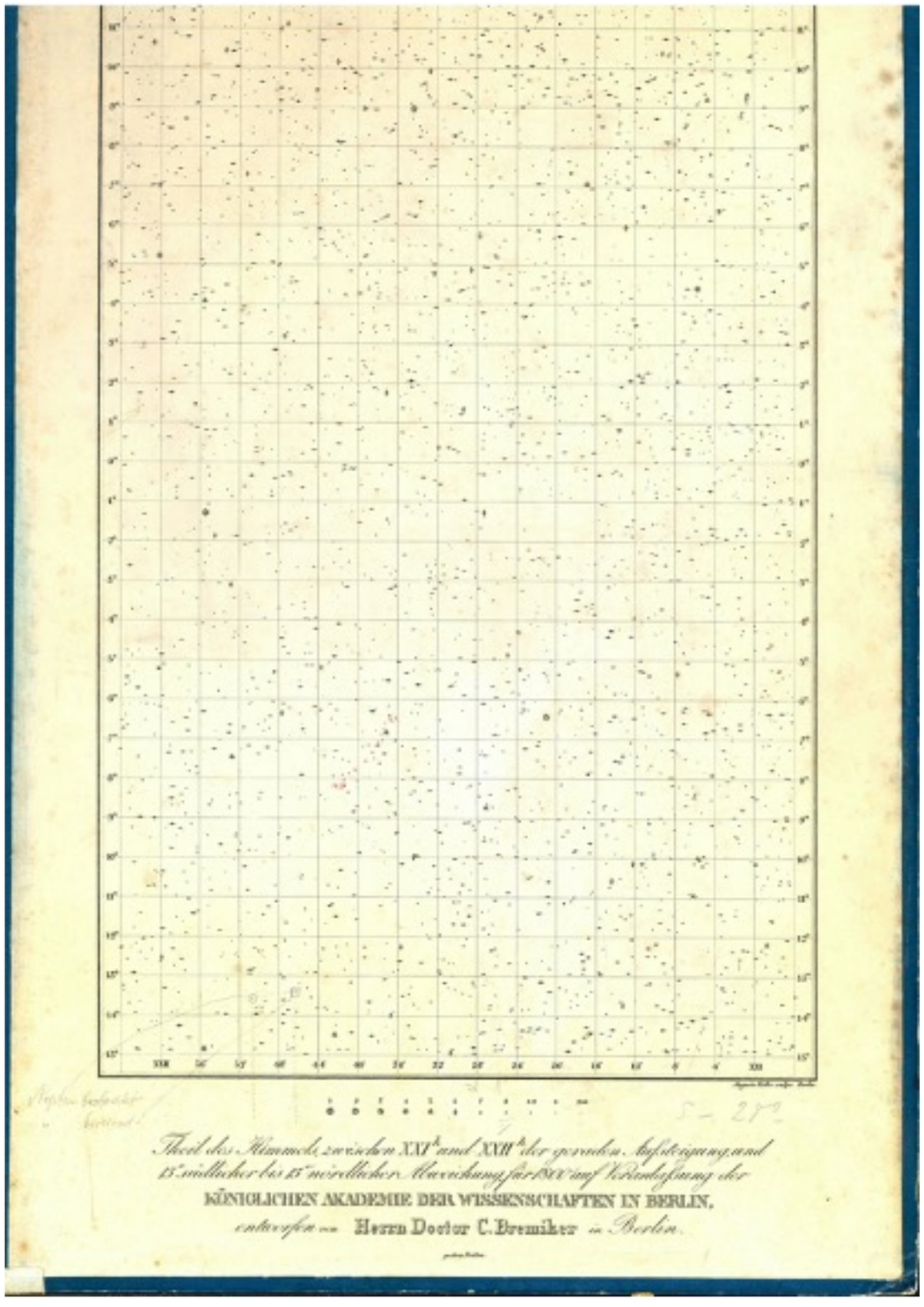




Atlas novus Coelestis (Harding 1822)

How did they find Neptune

- **Le Verrier suggested** they look for a **disk 3"** in diameter
  - very **difficult** in Berlin
  - Galle and d'Arrest **couldn't see anything like** a **disk** for some time
  - they turned to the **Harding's map**, there were too **many stars missing** from this map
- **d'Arrest remembered** that there should be a **new map** in **Encke's office** of the same sky region
- **Galle knew** where these **maps were** and they went to Encke's office and **got it**
- back in the dome, **d'Arrest is at a disk with the chart, Galle at the telescope**
- "**That star is not on the map**", said d'Arrest (at some time after 22:00 local Berlin time)
- **Encke's party** is **interrupted**: all 3 do further observations
- **waiting** for the next night: 24 Sept
- night is sufficiently clear to see that the **"star" has moved** in the predicted direction



Encke's announcement

Halbe gr. Axe 36,154. Umlaufszt. 217,387 Jahre (sider.)
Excentricität 0,10761. Perihel 284°45′
1847 Jan. 1. Mittl. Länge ..... 318 47. Masse $\frac{1}{9300}$,
und daraus hergeleitet 1847 Jan. 1. helioc. wahre Länge 326°32′
Entfernung von der Sonne 33,06

Durch einen am 23sten Septbr. hier angekommenen Brief forderte Herr *le Verrier* Herrn Dr. *Galle* besonders auf sich darnach umzusehen, wahrscheinlich leitete ihn die in seiner Abhandlung ausgesprochene Vermuthung dafs der Planet durch eine Scheibe sich kenntlich zeigen werde.

Denselben Abend verglich Herr *Galle* die vortreffliche Karte, welche Herr Dr. *Bremiker* gezeichnet hat (Hora XXI der akademischen Sternkarten) mit dem Himmel und ward fast sogleich sehr nahe an dem Orte den Herr *le Verrier* bestimmt einen Stern 8t. Gr. gewahr der auf der Karte fehlte. Er wurde sofort mit einem *Bessel*schen Sterne zu 3 verschiedenen Malen (immer bei 5 Beobachtungen) von Herrn *Galle* und dann auch einmal von mir verglichen. Diese Vergleichungen ergaben

Encke 1846, AN

- Encke mentions Galle only (no d'Arrest)
- highlights the role of the Hora XXI chart
- **two consequences**:
  - "nobody" new of d'Arrest's role until ~1876 (after d'Arrest death)
  - created a myth about the easy discovery
  - created a myth about the special chart that was only in Berlin
    - often used to justify why Challis did not discover Neptune
    - used as the reason why Le Verrier wrote to Galle

> By a letter that arrived here on 23rd Sept. Mr. Le Verrier asked Dr. Galle especially to look after it [the planet], probably led by an assumption, pronounced in his treatise, that the planet will be identified by a disc. The same evening **Mr. Galle** compared the excellent map, drawn by Mr. Dr. Bremiker (**Hora XXI of the academic star charts**), with the sky and **noted immediately** that very close to the position determined by Mr. Le Verrier a star of the 8th magnitude was missing in the map. (Encke, 1846:49-50)

The visionary project

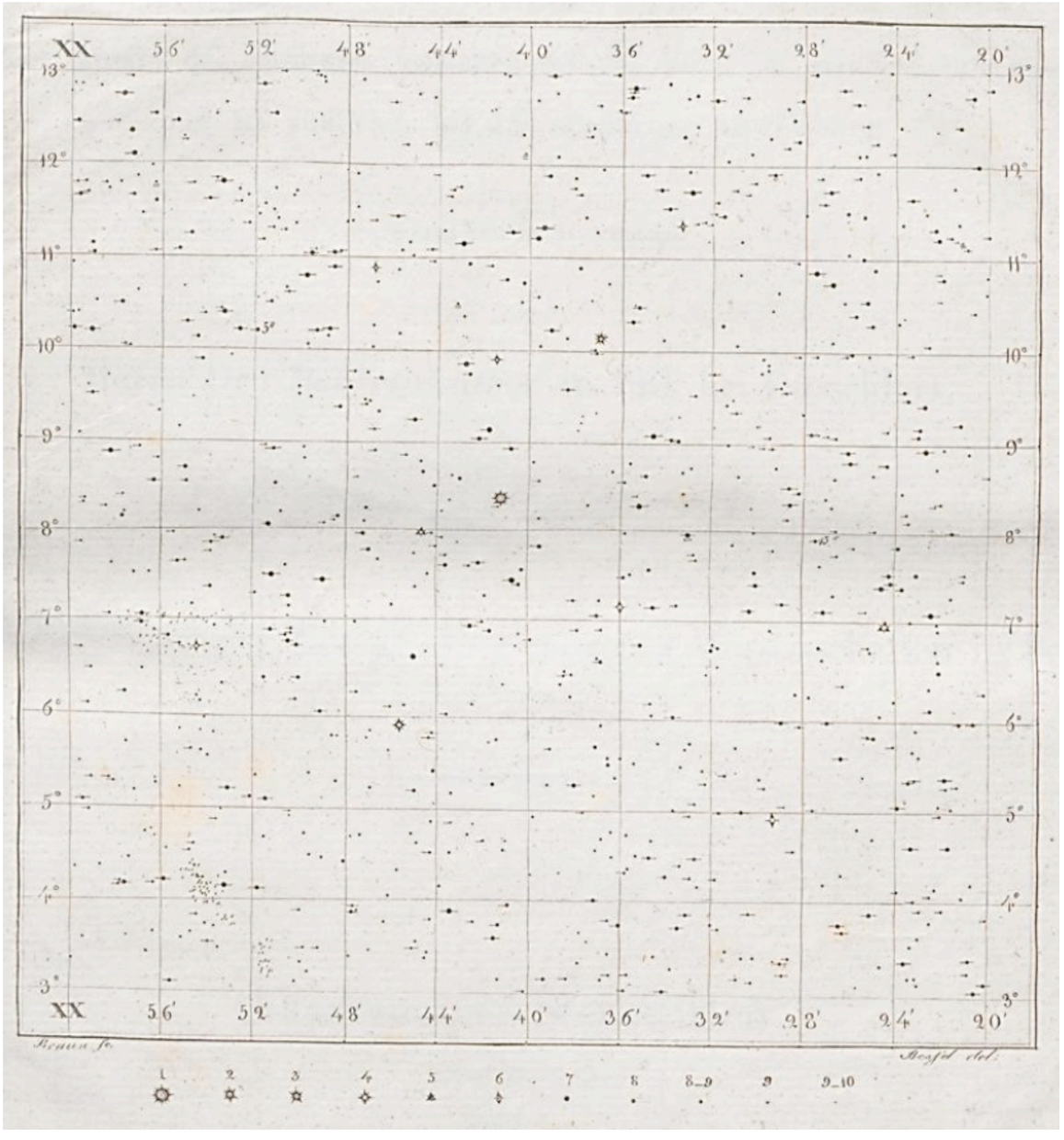
Academy Sky chart project

- **Friedrich Wilhelm Bessel**'s idea
- **1st idea** for **charting** region around **the ecliptic** appeared to **Franz Xaver von Zach** and his "**Celestial Police**" (Johann Hieronymus Schröter, Karl Ludwig Harding and Heinrich Wilhelm Olbers)
  - they wanted to **search for a planet** in the Titius-Bode gap **between Mars and Jupiter** --> **found 3(+1) asteroids 1801- 1807**
    - **Harding** eventually (1822) produced an **atlas** (which was widely used)
- **Bessel** was aware that **Harding's atlas** was **not complete** and would **not be very useful** in searching for additional solar system bodies (or for determining the location of comets)
- **15 October 1824** Bessel sends a **proposal to Berlin Academy of Sciences** for a **sky mapping** project

Friedrich Wilhelm Bessel (1784-1846)

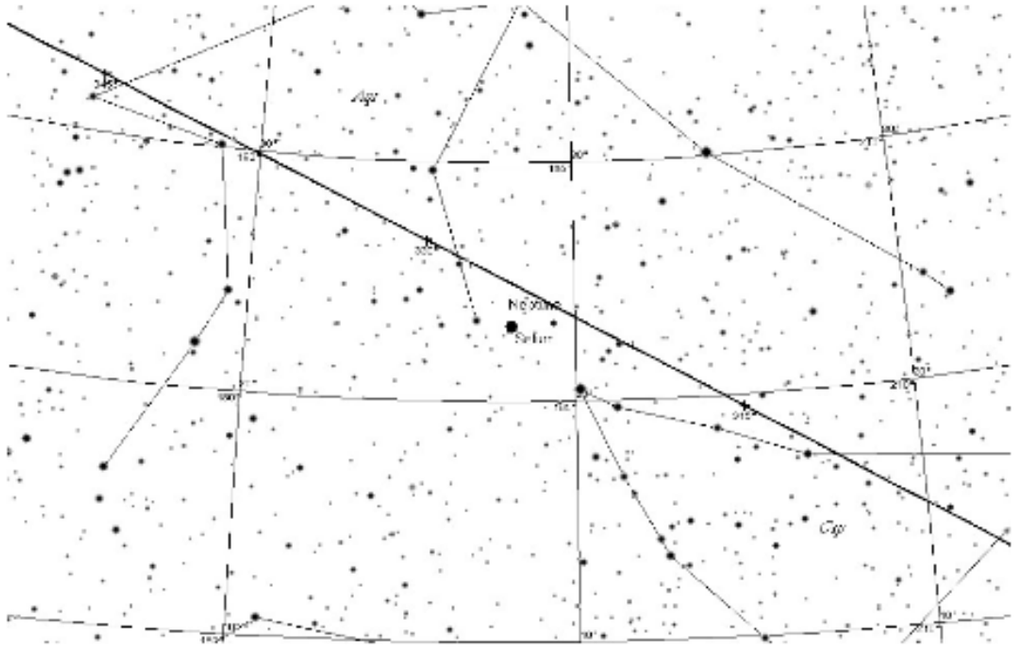
Bessel's proposal

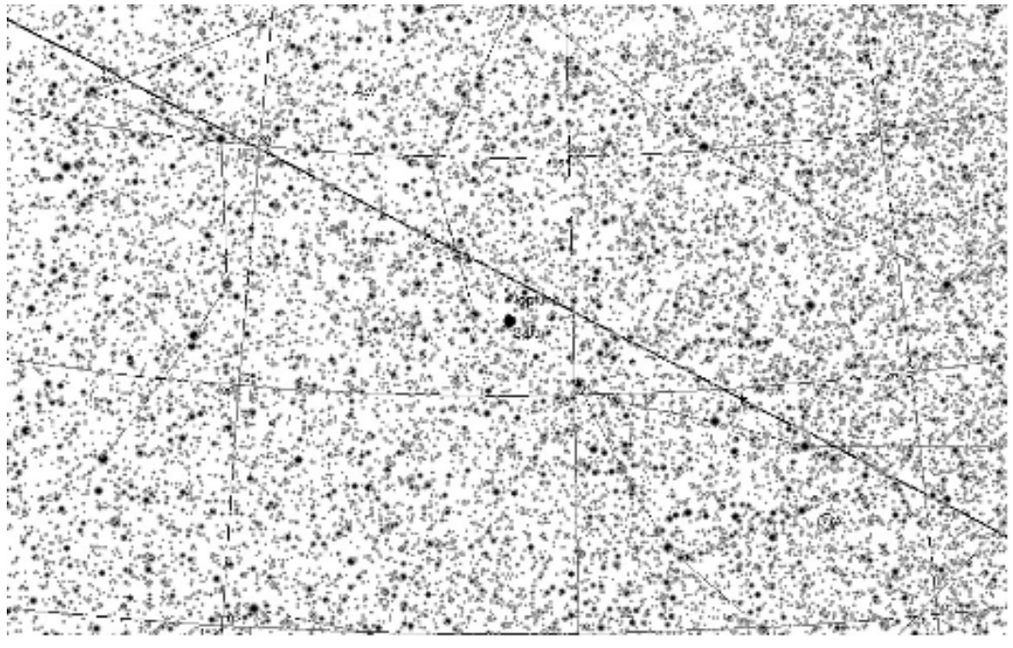
- Project outline:
  - the **map** should include stars between **15º North and 15º south of the ecliptic**, divided in **24 zones** (1h + 4min on each side)
  - **each zone** should be divided into **510 squares, 1º** in width and height
  - **reward** of **20-25 Dutch Ducats** for makers of the map
  - the **Academy** should **set up a commission** to take charge of the **project** and the **awarding** of the **prizes**
  - each map should be **cast in copper** so that it could be **reproduced at will later**
  - a **summary of the project** would be made available
- **Bessel** produced a **trial map**, provided **guidelines** how to **observe and make the map**, and his student **Carl Steinheil** designed an **apparatus for plotting** (Steinheil 1826, Staubermann (2006)



A major undertaking

- **Bessel planned** that all stars to **~10mag** should be observed (complete down to the 9th magnitude)
- ideal **map makers** were "**Freunde der Wissenschaft**" (not the directors of main and well equipped observatories)
    - nevertheless, many established astronomers astronomers volunteered -- and not delivered
- **Encke** was placed **in charge** (1825)
- the goal was to **distribute the maps swiftly** to:





Sheen (2013)

die Royal Society in London
die Royal Astronomical Society in London
das Bureau des longitudes in Paris
das Institut de France in Paris
die Kais. Akademie zu Petersburg
die Königl. Akademie zu Neapel
den Herrn Hofrath Gaufs in Göttingen
den Herrn Dr. Olbers in Bremen
den Herrn Prof. Schumacher in Altona

Encke (1859), "Cataloge"

Sky Charts

- **24 charts**
- **34 years**
- **20 astronomers**
  - **total number** of astronomers working on the project: **36**
- the **Academy commission** had in total **7 members**, out **of 4 original 3 died** during the project (all except Encke)
- the **project** was **too long** and **too expensive**, until:
- **8 December 1845**
  - **Karl Ludwig Hencke** (retired postmaster) in Driesen (Drezdenko, Poland) using Hora IV discovered Astraea

Davor Krajnović

Hora	author	where	when
0	Robert Luther	Bilk bei Düsseldorf	1858
1	C.F.R. Olufsen	Copenhagen	1849
2	J.J.Morstadt	Prag	1835
3	L. H. d'Arrest	Leipzig	1854
4	K.Knorre	Nicolajew	1835
5	Argelander	Bonn	1856
6	C. Bremiker	Berlin	1853
7	S. Fellöcker	Kremsmüster	1848
8	Schwerd-Wolfers	Speier-Berlin	1833
9	C. Bremiker	Berlin	1858
10	Göbel	Coburg	1830
11	von Boguslawski	Breslau	1852
12	von Steinheil	München	1834
13	C. Bremiker	Berlin	1843
14	T.J. Hussey	Chislehurst	1831
15	Harding	Göttingen	1830
16	Wolfers	Berlin	1843
17	C. Bremiker	Berlin	1840
18	Inghirami-Capocci	Florenz-Neapel	1831
19	Wolfers	Berlin	1840
20	Henke	Driesen	1852
21	C.Bremiker	Berlin	1845
22	Argelander	Åbo	1832
23	Harding	Göttingen	1834

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		Åbo	1832
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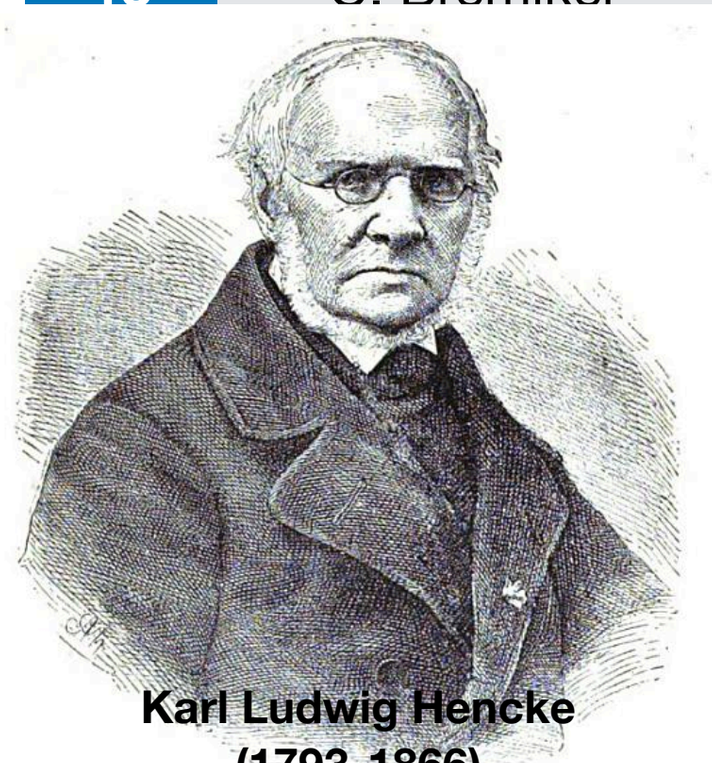


Karl Ludwig Hencke (1793-1866)

The problem with Hora XXI

- the map was **crucial** for the **discovery**
- it was **ready**, but **not distributed**
- Why was it only in Berlin?
  - and not in Cambridge!
- Did Le Verrier know of the existence of the map?
  - assumed by early "historians" of the discovery

> site instruments. Now, it so happened that the map of that precise region where the new planet was expected, had been completed by Dr. Bremiker; and it was printing, or just printed, at Berlin:—I believe that the Observatory of Berlin had obtained the proof-sheet. The Astronomers of this Institution were thus in a position of power regarding such inquiries, enjoyed by no other Observatory in existence: they had simply to notice Bremiker's Map and then the Sky—observing if

John Pringle Nichol, 1849, "Planet Neptune: An exposition and history"

> and employed with that quiet persevering energy, distinguishing Mr. Challis.—But be it recollected, AT CAMBRIDGE THERE WAS NO BREMIKER'S CHART. The sky in that region had to be

Why was the map in Berlin?

Shipped in pairs

- **maps** were **always** shipped **in pairs**
- **Hora XXI**
  - work started in **1826** by **Otto August Rosenberger** (Halle/Saale)
  - in **1831 Encke asks** what is the **status**, Rosenberger replies it **should be done** by **1833**
  - by **1839** there is **no** completed **map**
  - in **1840**: **Encke** decides to **change the astronomer** in **charge**
    - **Carl Bremiker** (his own past student); Rosenberger passes all data he collected
    - Bremiker **completes** it by **1841**, but **Encke reports** only in **1844** to the **Academy** that it is **finished** (probably due to verification)
    - **9 November 1845** it is **engraved** and **printed**
    - Encke **waits** for **another map** to be shipped!
- **Hora XI**
  - work started by **Palm Heinrich Ludwig Boguslawski** (Breslau/Wrocław)
  - **12 June 1845** completed first draft
  - **February 1846** printed in Berlin and **sent** to Boguslawski **for verification**
  - **not returned until 1851**
- **Hora XXI** was **just another map** in a large and long project, not at all special (until 23. September1846)

Otto August Rosenberger

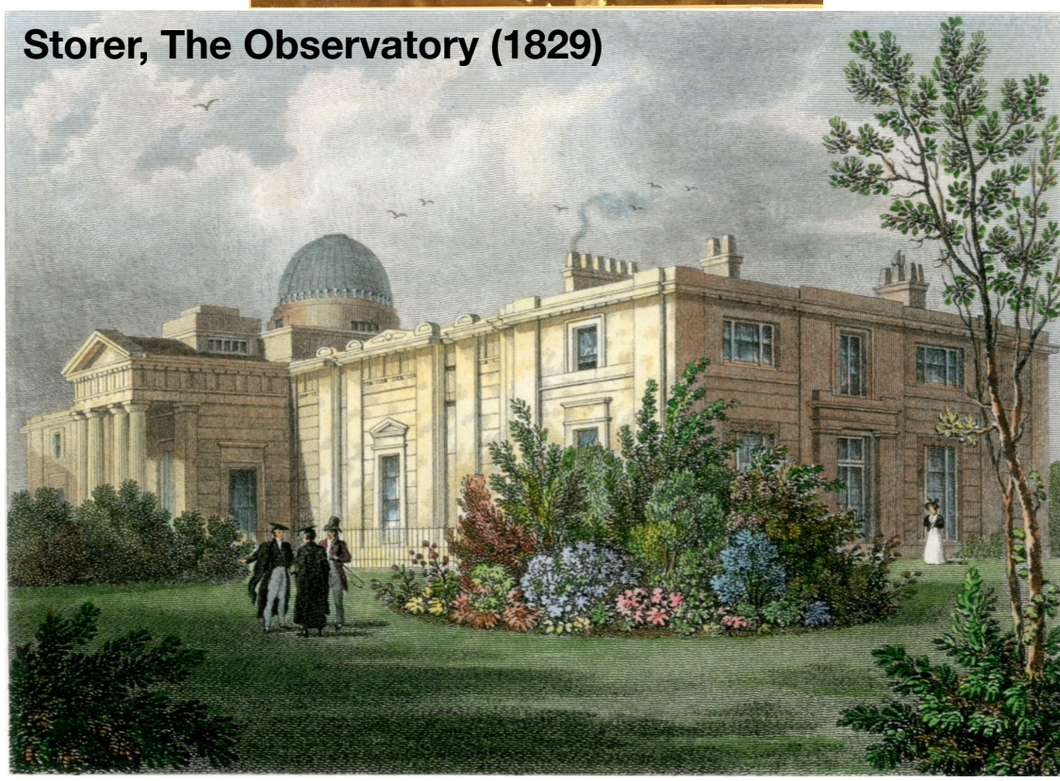
- Hora IV:
  - made by Karl Friedrich Knorre in Nikolayev
  - completed 1834, distributed 1837 (with Hora II)
  - 1845 used by Hencke to discover the 1st new (minor) planet since 1807!

Mapless in Cambridge

- Challis conducts a "secret" search mapping the sky within a rectangle of about 30x10 degrees centered on the predicted position: Starts on **29.07.1846**
- on **04.08.** and on **12.08** observes Neptune, but doesn't do reduction and the **planet is not discovered**.
- on **29.09.** reads **Le Verrier's** latests **prediction**, stops the search, goes to **Le Verrier's positions** and **observes a star** with "an appearance of a disk", but **does not** subsequently **verify** if it is a star or a planet
- on 30.09. finds out about the discovery in Berlin....
- "**Not having hour XXI of Berlin star-maps - of the publication of which I was not aware - I had to proceed on the principle of comparison of observations made at intervals**", Challis, 17.10.1846, The Athenaeum
- "**Unfortunately I was not then aware of the publication of hour XXI of the Berlin Star-maps, and consequently had to proceed on the principle of comparison of observations made at intervals.**" Challis, 1847, AN, 25, 105 (letter from 21.10.1846)
- "**If I had had this map ..., I should have compared my field of view with the map at once.**" Challis, 1847, MNRAS, 7, 145 (presented on 13.11.1846)

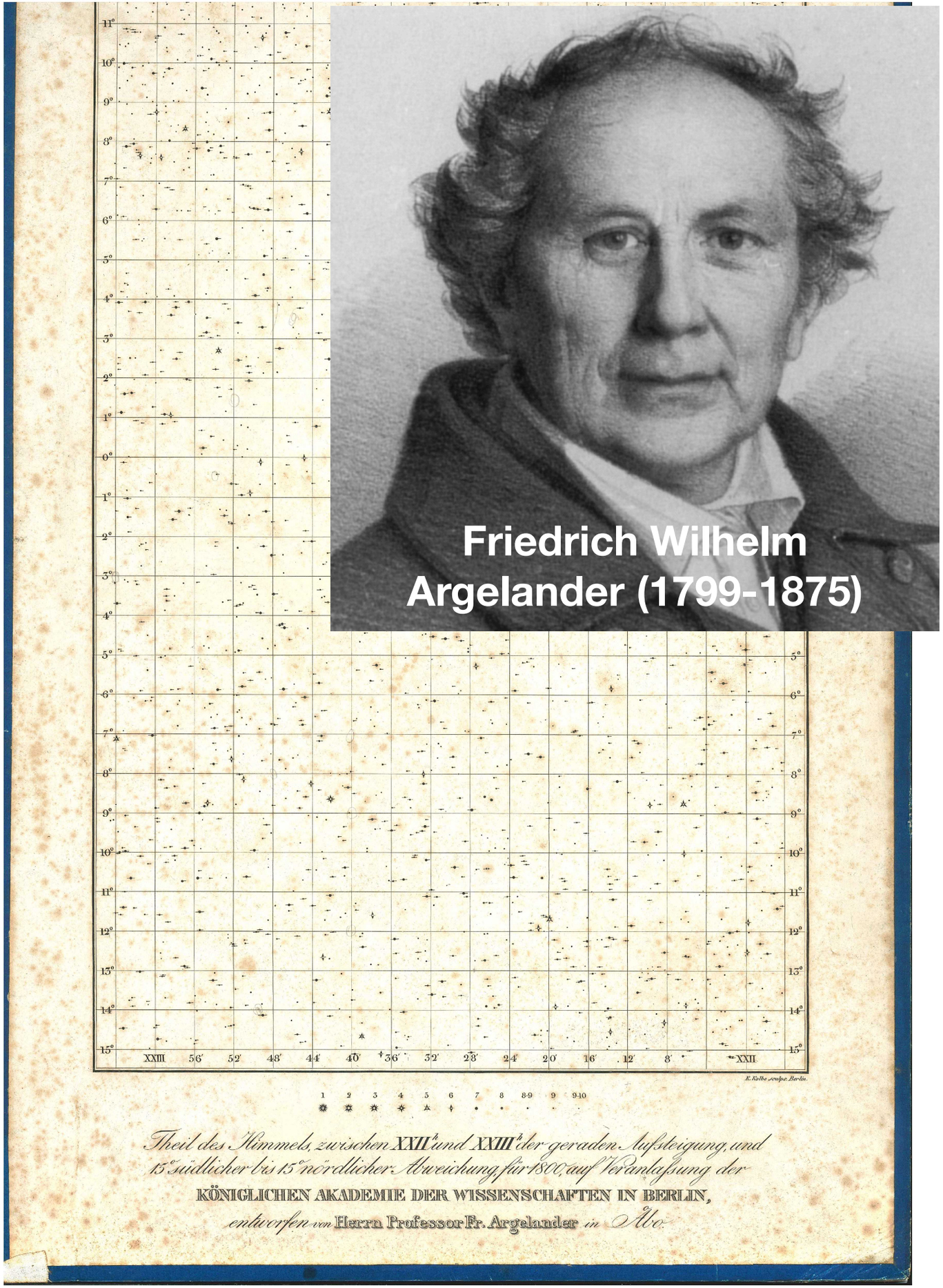
James Challis (1803 - 1882)

Storer, The Observatory (1829)

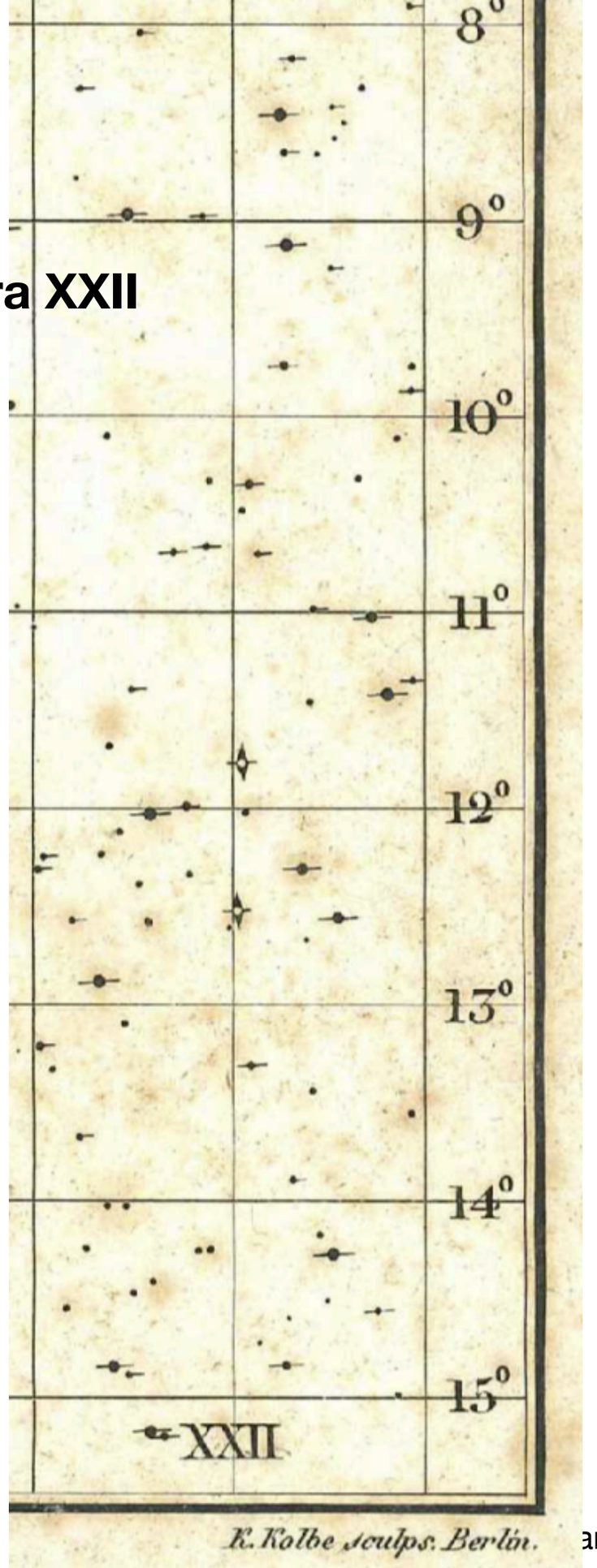


Mapless in Cambridge?

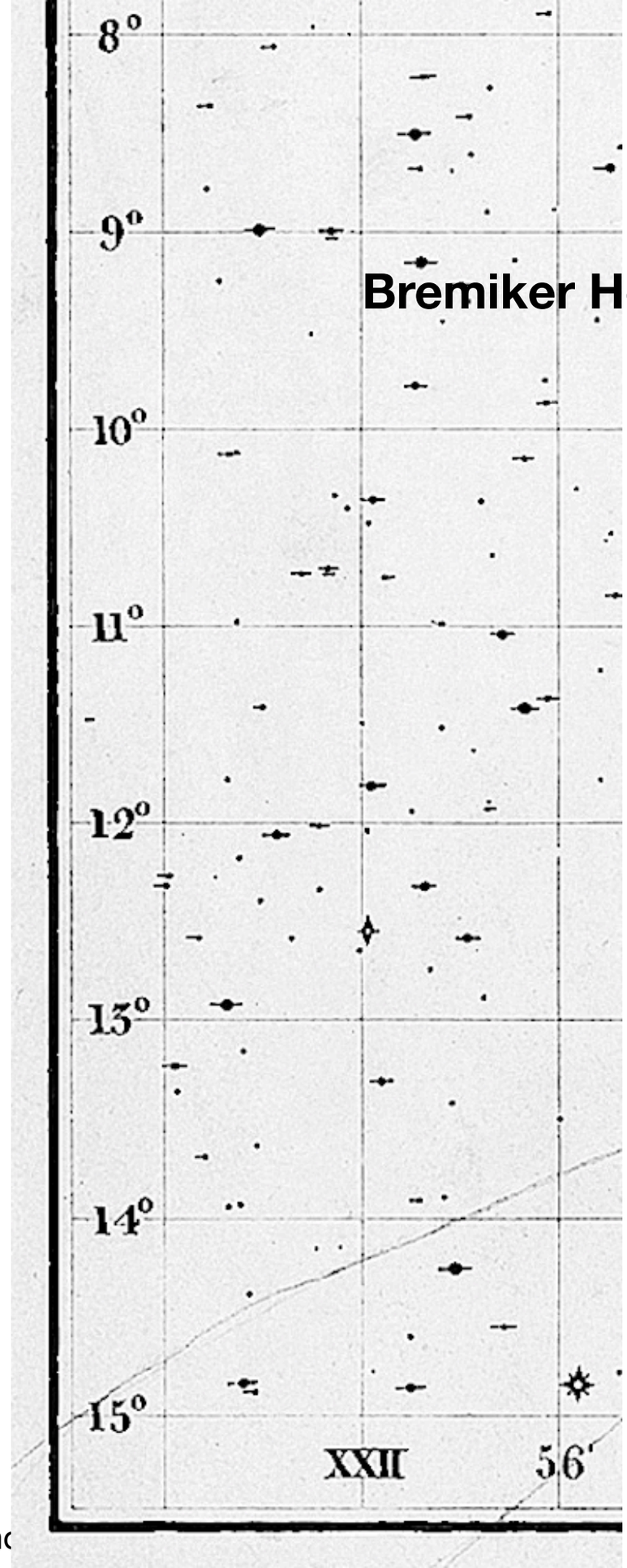
- Hora XXII by Argelander
- published in 1833
- in a letter (21.07.1846) Airy to Challis: "**There is only one [map] which applies partially to this inquiry**"
- confirmed to have been in Cambridge
- Friedrich Wilhlem Argelander
  - Bonner Durchmusterung (BD) 1859 - 1903
  - survey of the full sky (10x #stars of Academy Star Charts)



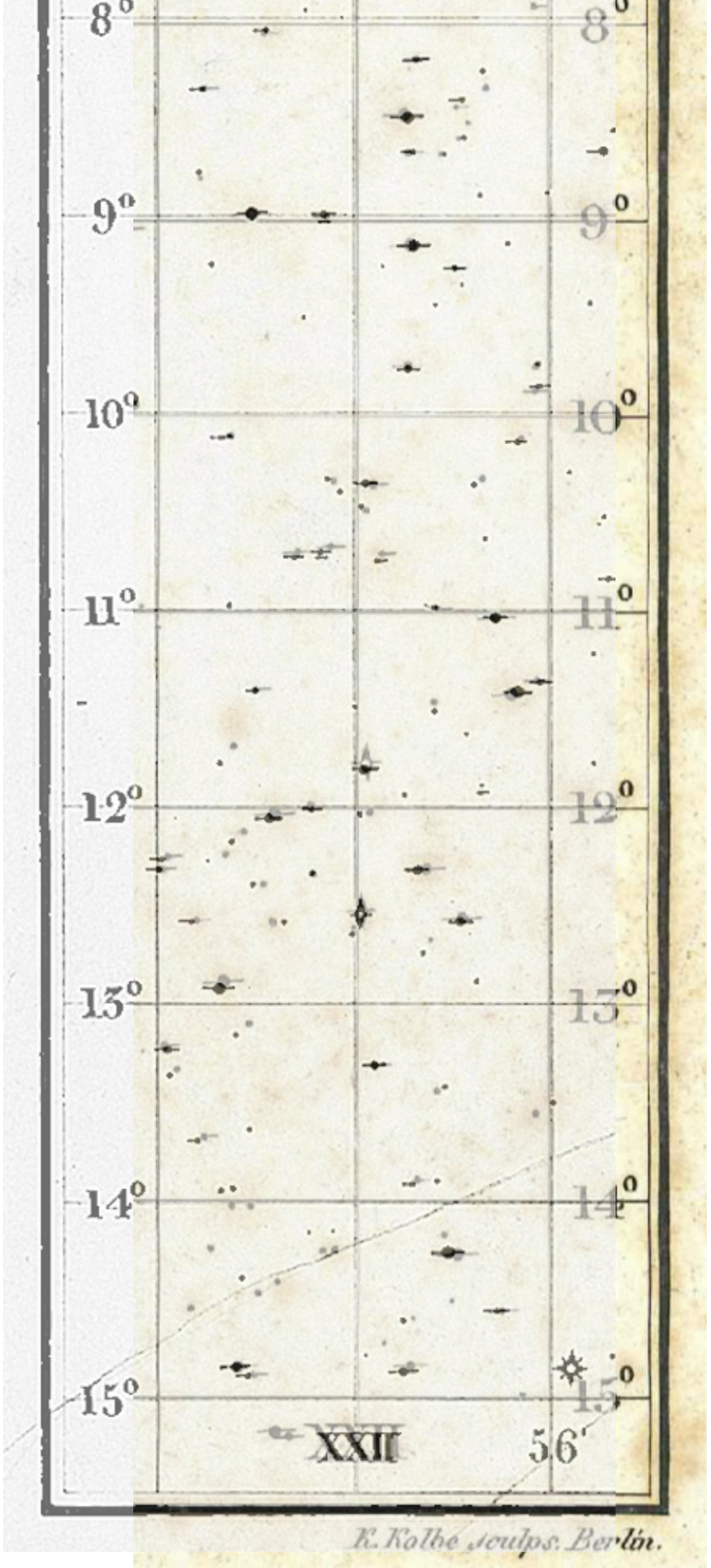
Argelander Hora XXII



Bremiker Hora XXI

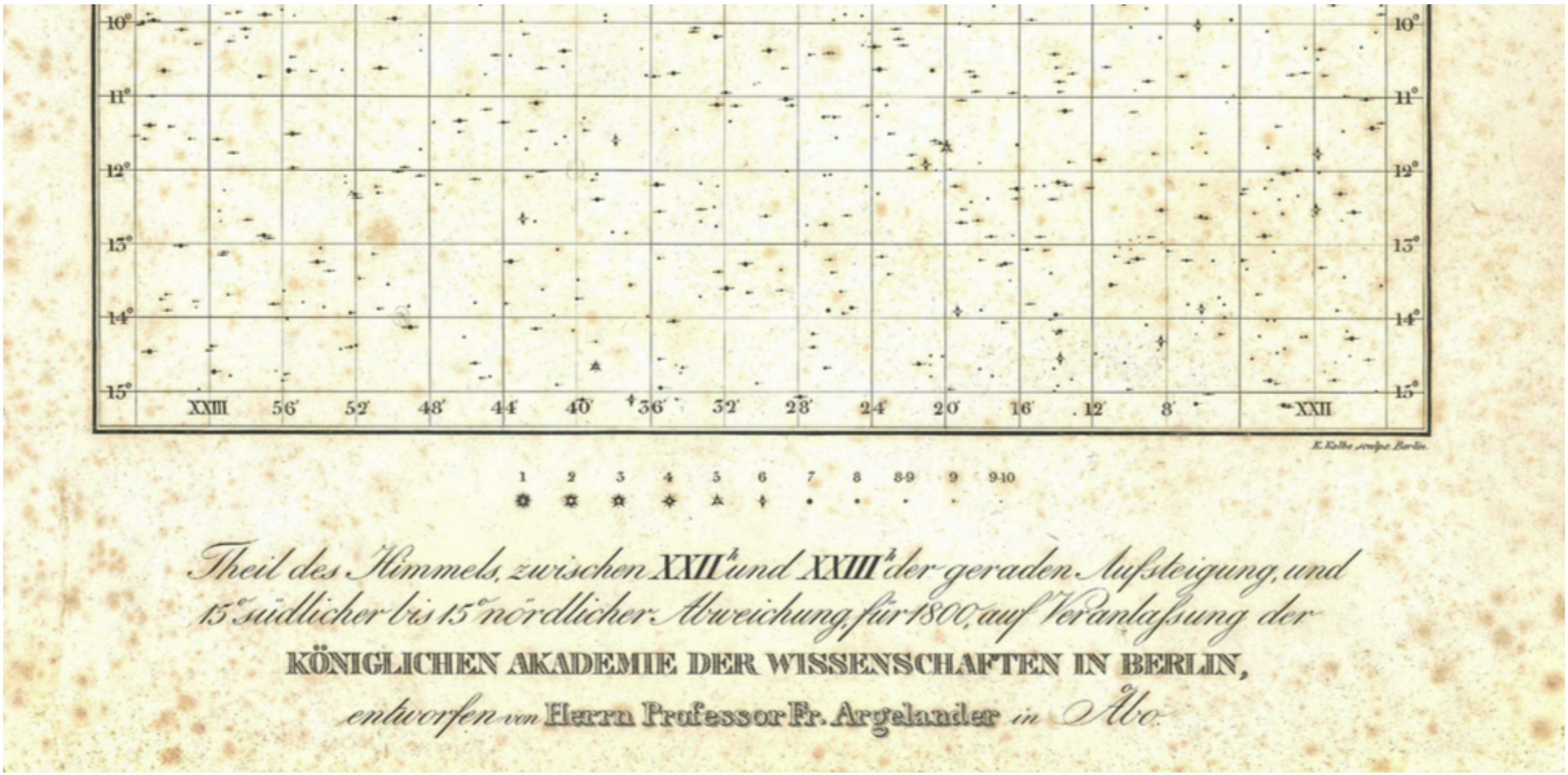


Argelander Hora XXII



Bremiker Hora XXI

Where was Neptune on 29.07.1846?



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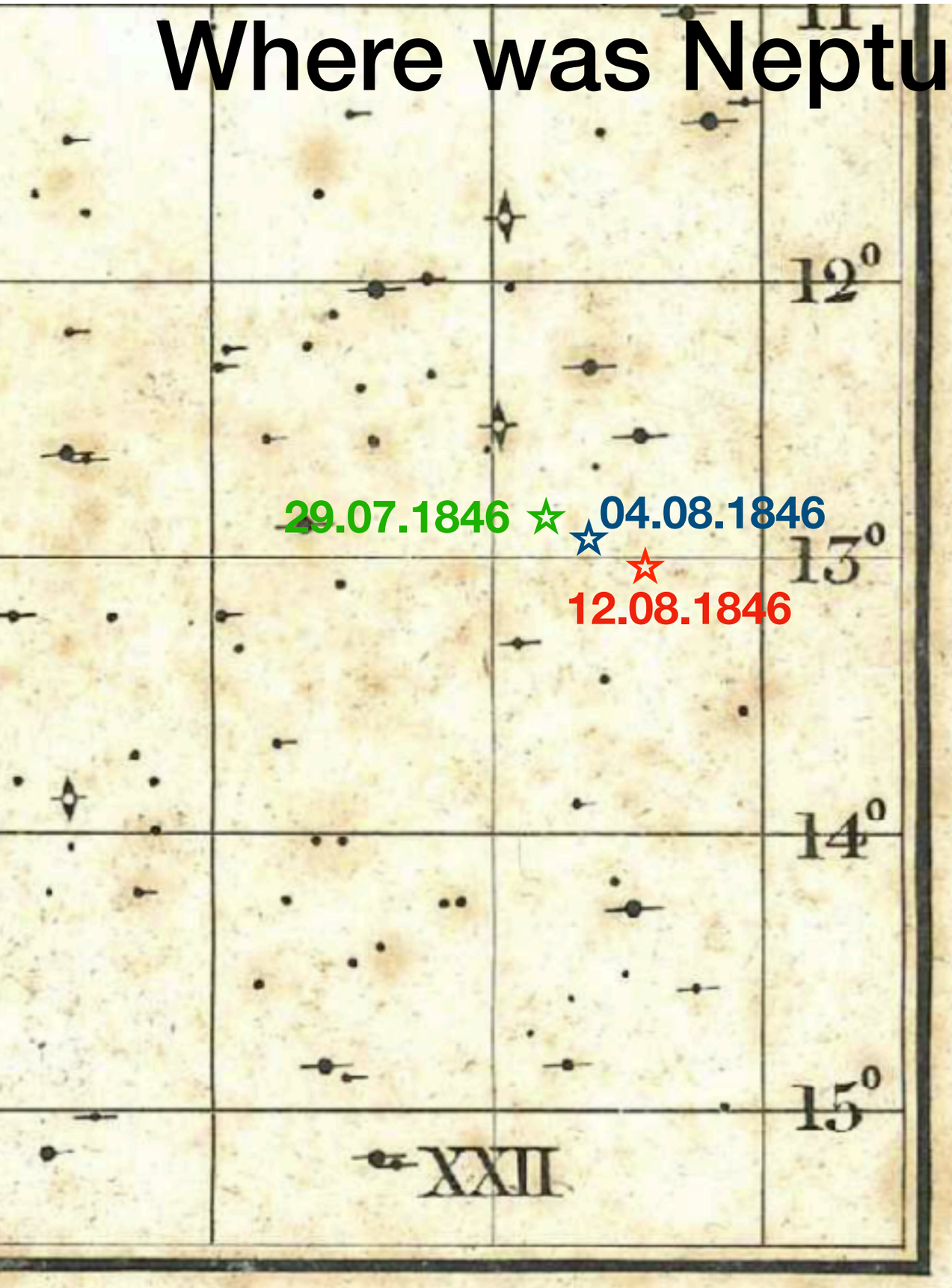
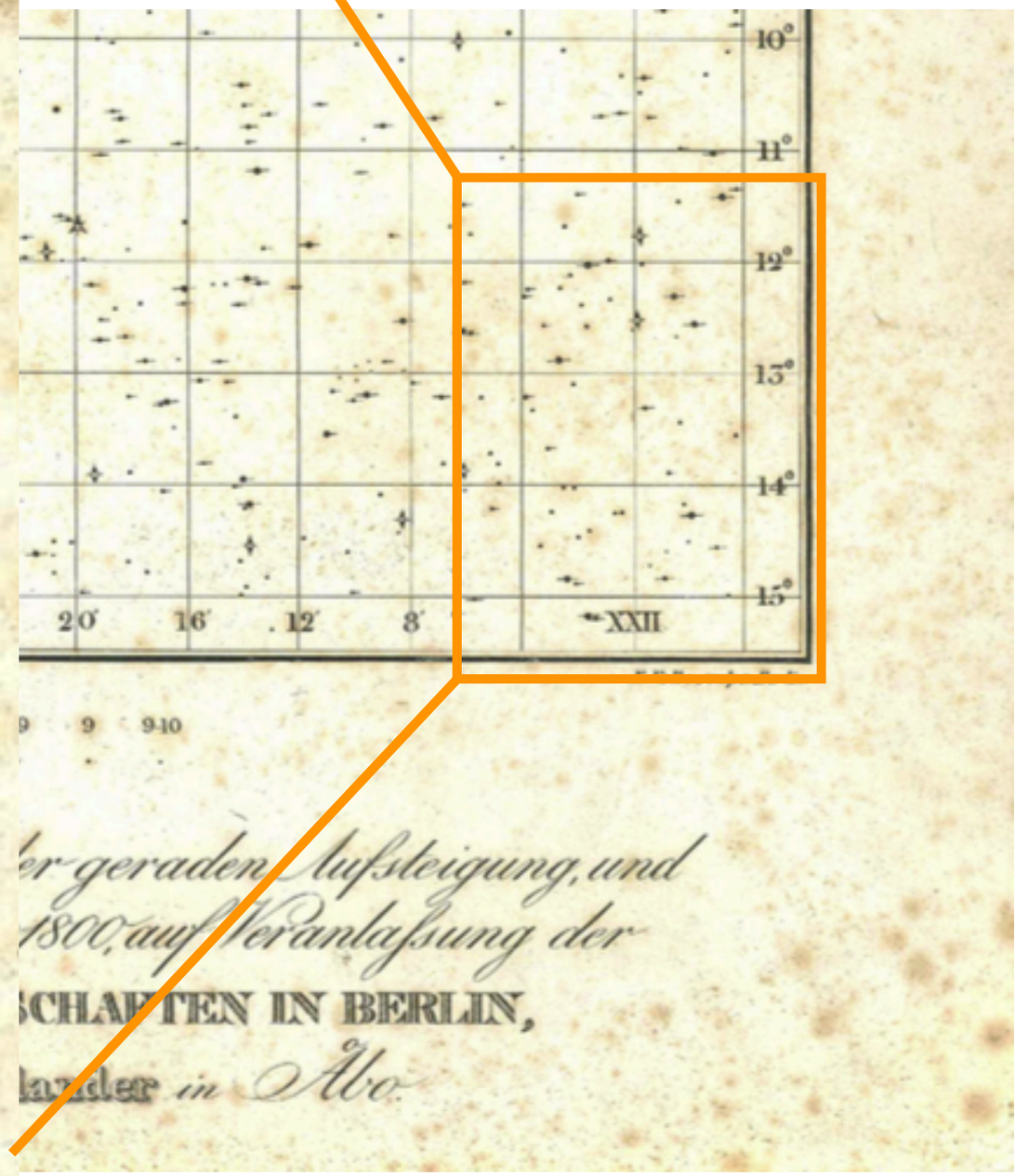




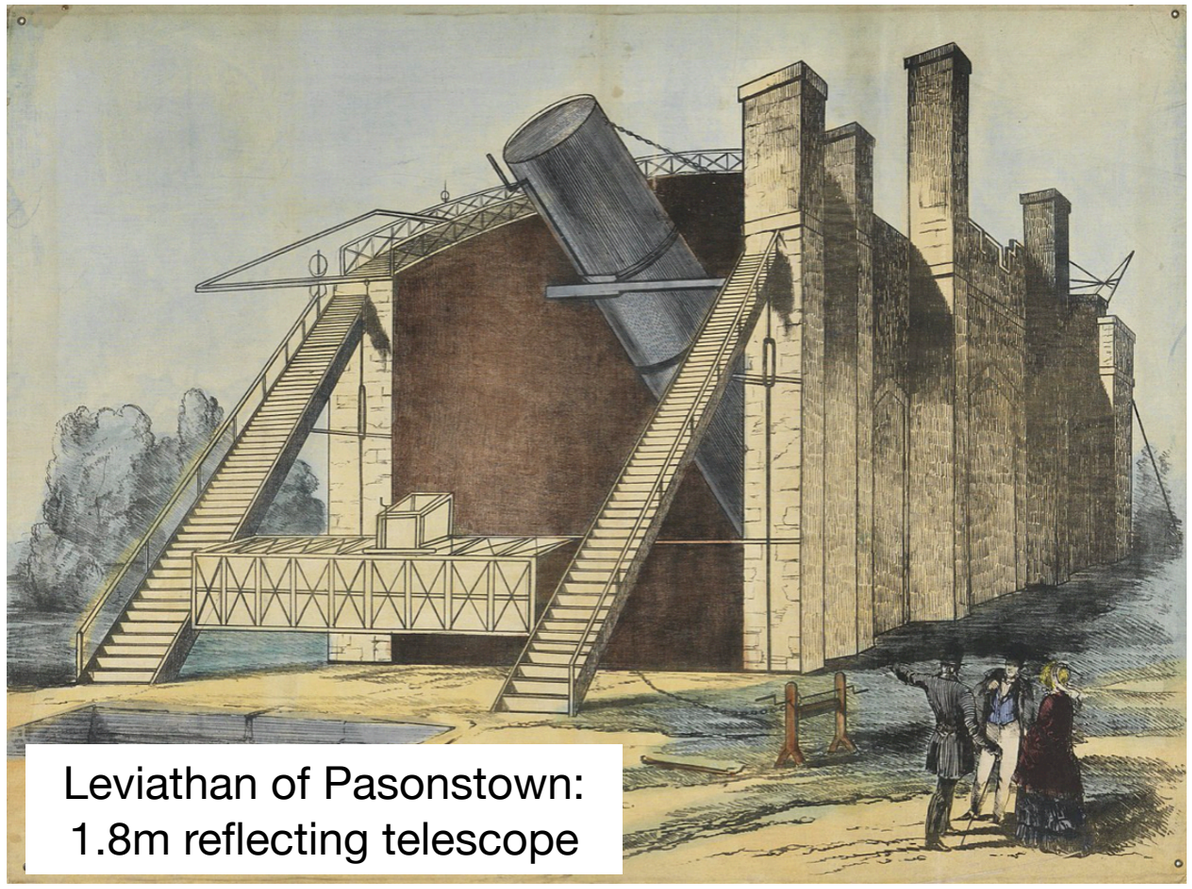
Le Verrier's lucky choice?

Why did Le Verrier write to Galle?

- Encke's letter to Le Verrier (Centenaire, 1911):
  - "I dare say that **without a letter** you have kindly **ad**
    Mr. Galle, the search **would not have been made i**
- Because he **knew there was a map in Berlin**?
  - stated as late as 1911 (Foerster, 1911)
  - Le Verrier never claimed that
  - Galle explicitly refuted it (Galle 1882)
- **Map** is **not** the **reason**:
  - Le Verrier **also** sent **a letter** to **Otto Struve** (in Pulkovo Observatory)
  - even Hora IV was used to discover Astraea, the **maps were not really "popular"** (e.g. mapless in Cambridge)
  - Le Verrier's letters to Galle and Struve focus on the fact that the **planet should be visible as a disk**
- **Schumacher's idea** (30 June 1846): contact people with best telescopes:
  - **Struve (Russia)** and **Lord Rose (Ireland)**
  - Le Verrier (1811) **does not contact directors**:
    - Johann Galle (1812) - **assistant**, Otto Struve (1819) - **assistant/son of the director**
- why Galle?
  - **Galle sent his PhD thesis** (on Mercury observations) to Le Verrier in 1845

Le Verrier to Galle (18 September 1846)

D'ailleurs, la grandeur de sa mass epermet deconclure que la grandeur de son diamètre apparent est de plus de 3″ sexagéssimales. Ce diamètre est tout-à-fait, de nature à être distingué, dans les bonnes lunettes, du diamètre fictive que diverses aberrations donnent aux étoiles.



Leviathan of Pasonstown:
1.8m reflecting telescope

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Le Verrier to G

D'ailleurs, la
grandeur de
géssimales.
tingué, dans l
es aberration

OLAI ROEMERI

TRIDUUM

OBSERVATIONUM ASTRONOMICARUM

A. MDCCVI. DIEBUS M. OCT. XX. USQUE AD XXIII. INSTITUTARUM

REDUCTUM ET CUM TABULIS COMPARATUM

DISSERTATIO

QUAM

CONSENSU ET AUCTORITATE

AMPLISSIMI PHILOSOPHORUM ORDINIS

IN

UNIVERSITATE LITTERARIA FRIDERICA GUILELMA

PRO SUMMIS

IN PHILOSOPHIA HONORIBUS

RITE CAPESSENDIS

DIE I. M. MARTII A. MDCCCXXXV.

PUBLICE DEFENDET

AUCTOR

IOANNES GODOFREDUS GALLE

SAXO BORUSSUS

OBSERVATORII REGII ADIUNCTUS.

OPPONENTIBUS:

I. Fr. Wolters, Ph. Dr. Ephem. astr. Berol. Calc. p
B. Jacobs, gymn. reg. Joachim. Prof.
G. Michaelis, Ph. Dr. gymn. Frideric. Collab.

BEROLINI

TYPIS ACADEMICIS.

MDCCCXXXV.

L

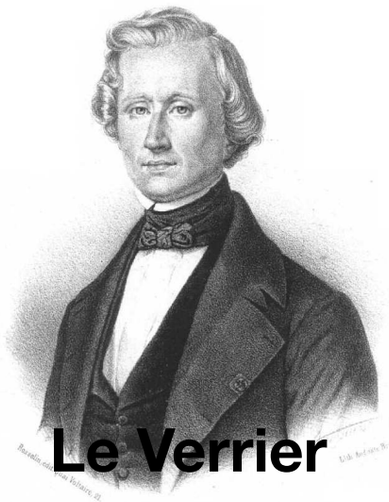
1.8m reflecting telescope

German scandals

Where is d'Arrest?

- **Galle to Le Verrier, 25.09.1846**
  - "The planet whose position you had indicated really exists. On the very day I received your letter **I found** an 8th mag. star, which did not appear in the excellent chart Hora XXI..."
  - "... the diameter seemed near 3"; however, one can only be sure in case of very favourable atmospheric circumstances, and it is **mainly the chart** that facilitated the search"


Galle


Le Verrier

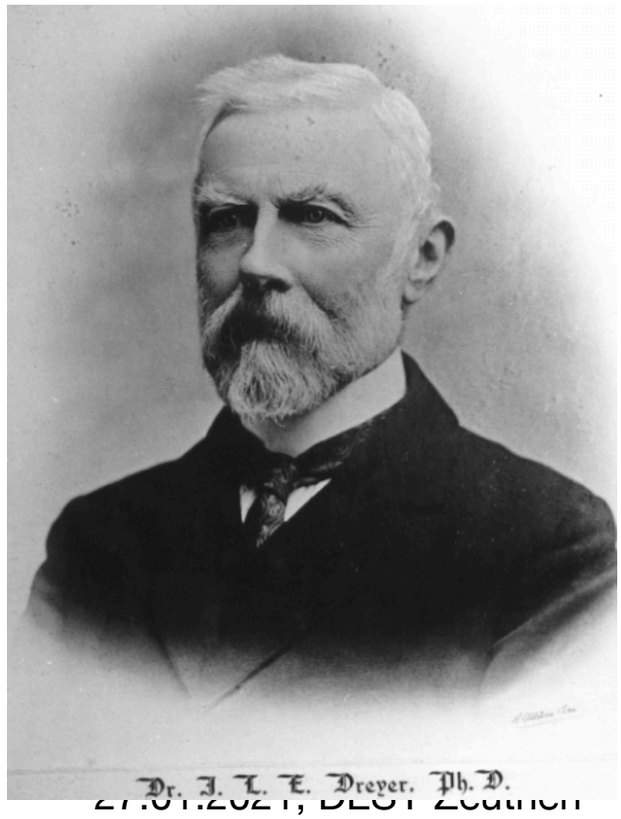
- **Encke 1846, AN, 25, 49, Nr. 580** (sent on **26.09**, received on **29.09**, printed on **12.10**)
  - on 23.09.1846 a letter arrived from **Le Verrier to Galle** asking him to search for the planet based on his prediction and the fact that the planet can be recognised as a disk
  - "On the same evening **Galle compared corresponding map**, made by Dr. Bremiker (Hora XXI), with the sky **and found** very closely to the location predicted by Le Verrrier, a star of 8th magnitude, which was missing on the map."
  - "Es ist überflüssig noch etwas hinzuzusetzen"


Encke

The long silence

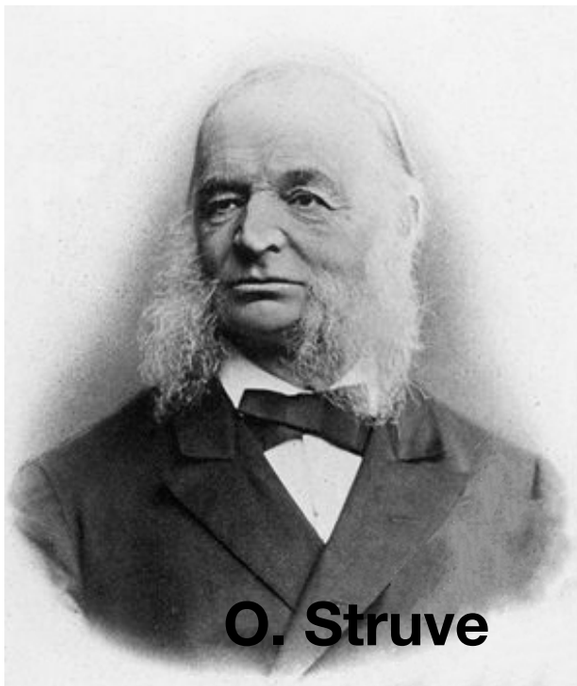
- nothing much (different) in print until 1876(!)
  - John Dreyer, Obituary of d'Arrest, 1876, Vierteljahrschr.Astron.ges.11,1
    - "und war als Galle's Gehülfe thätig, als dieser am 23.09.1846 den Neptun auffand"
- but not in Obituary in MNRAS (1847, 36, 155) (by some other author!)

The first ever mention of d'Arrest's role in print!



The rumours

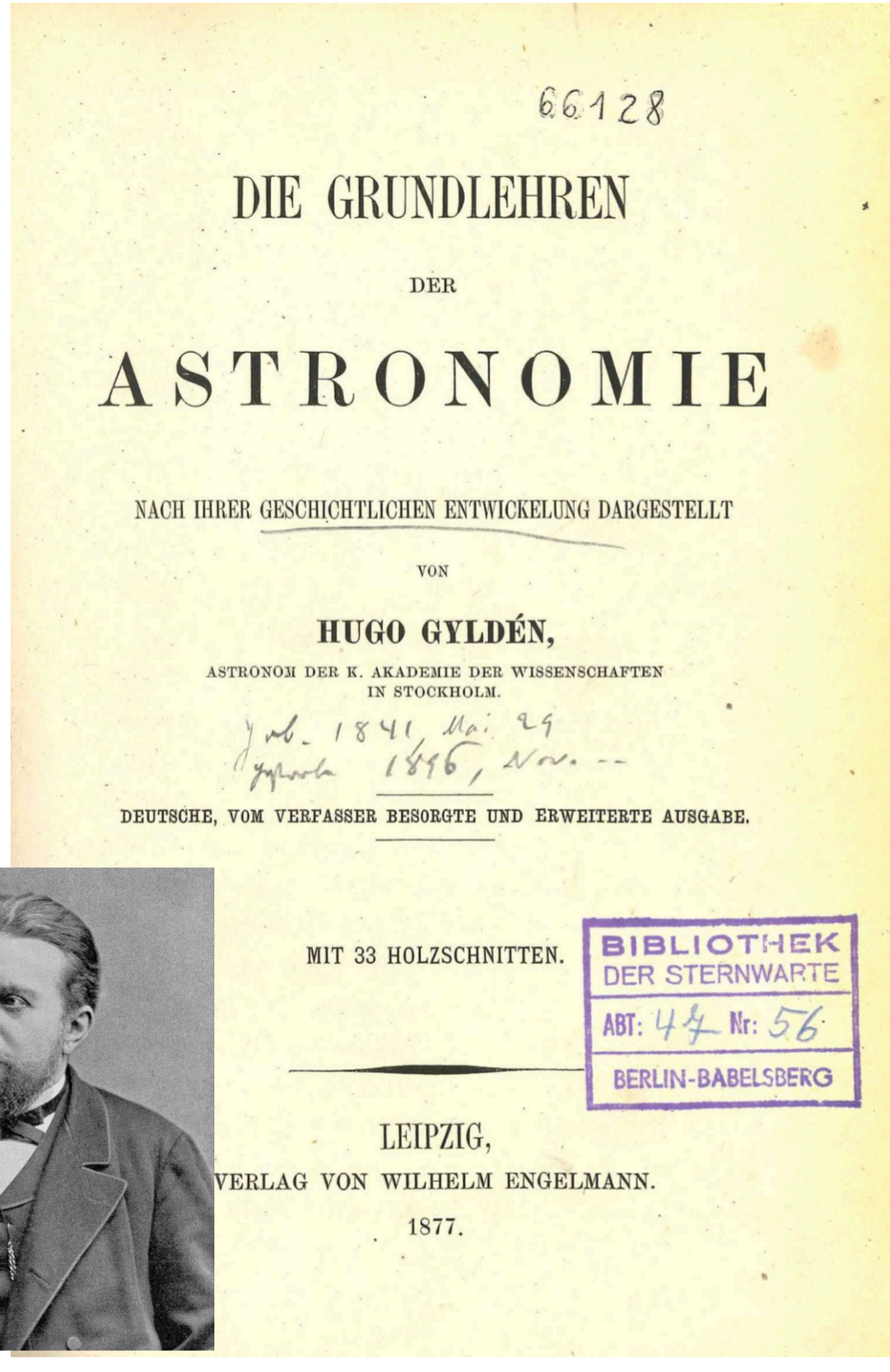
- **1856 Otto Struve** visited Encke in Berlin (from Struve's **unpublished memoirs**!) :
  - I was surprised by a visit from Encke, who embraced me by saying casually: '**You took a heavy weight from my heart by placing d'Arrest** in such a favourable position [director of Kiev Observatory]; **I have constantly been remorseful that I attributed the actual discovery of Neptune solely to Galle** and, if possible, in his favour, while the **principal merit of the discovery is due to d'Arrest**" (Dick 1986, Die Sterne, 62, 5)
  - "**Galle had no confidence** in **Le Verrier's calculations** and **had made no preparations** for finding the planet in the sky, **but d'Arrest had done so**, calculated the position in advance and **prepared everything for the first favourable evening**, to make a survey of the area of the sky in question, by **comparing it with the first draft of Bremiker's map**. **Galle had approached** [the telescope], and, because d'Arrest was already a little weary, **proposed to temporarily replace him** at the refractor. It **coincidentally happened** that in one of **the first objects that Galle had registered** in the sky, d'Arrest, who had compared Galle's information with that map, had to declare that this object **was not on the map**. With that, the planet was discovered and in that it **must be admitted that Galle was the first** to have seen the planet as such in the sky." (Dick 1986, Die Sterne, 62, 5)
- Rumours:
  - d'Arrest calculates the position on the sky
  - d'Arrest prepares observations
  - d'Arrest prepares Hora XXI
  - Galle (kind of) joins in, looks through the telescope and finds the planet
  - Galle observes, d'Arrest checks the map



Veni Vidi Vici

- Hugo Gyldén (1841 - 1896): "Die Grundlehren der Astronomie"

- "When the **news of Paris arrived** at the Berlin Observatory, the then assistant to the observatory, **Mr. d'Arrest hurried to design** a small **map of the designated area** of the sky to facilitate the search for the planet. As soon as **he had pointed the telescope** to the relevant celestial region, the **observer Dr. Galle arrived**, **looked** into the telescope and - **saw** the planet." (p. 248)



Popular Astronomv

Early in September, 1846, while Professor Challis was still working away at his observations, entirely unconscious that the great object of search was securely imprisoned in the pencilled figures of his note-book, Leverrier wrote to Dr. Galle, at Berlin, suggesting that he should try to find the planet. It happened that a map of the stars in the region occupied by the planet was just completed, and on pointing the telescope of the Berlin Observatory, Galle soon found an object which had a planetary disk, and was not on the star map. Its position was carefully determined, and on the night following it was re-examined, and found to have changed its place among the stars. No further doubt could exist that the long-sought-for planet was found. The date of the optical discovery was September 23d, 1846. The news reached Professor Challis October 1st, and, looking into his note-book, he found his own observations of the planet, made nearly two months before.

POPULAR ASTRONOMY.

BY

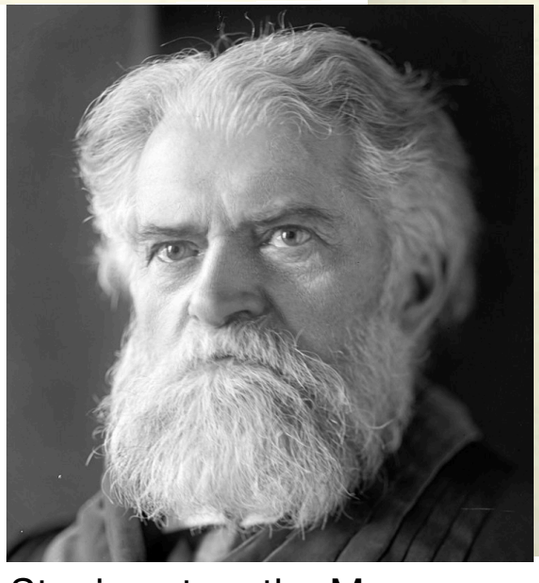
SIMON NEWCOMB, LL.D.,

PROFESSOR, U. S. NAVAL OBSERVATORY.

WITH ONE HUNDRED AND TWELVE ENGRAVINGS,
AND FIVE MAPS OF THE STARS.

London:
MACMILLAN AND CO.
1878.

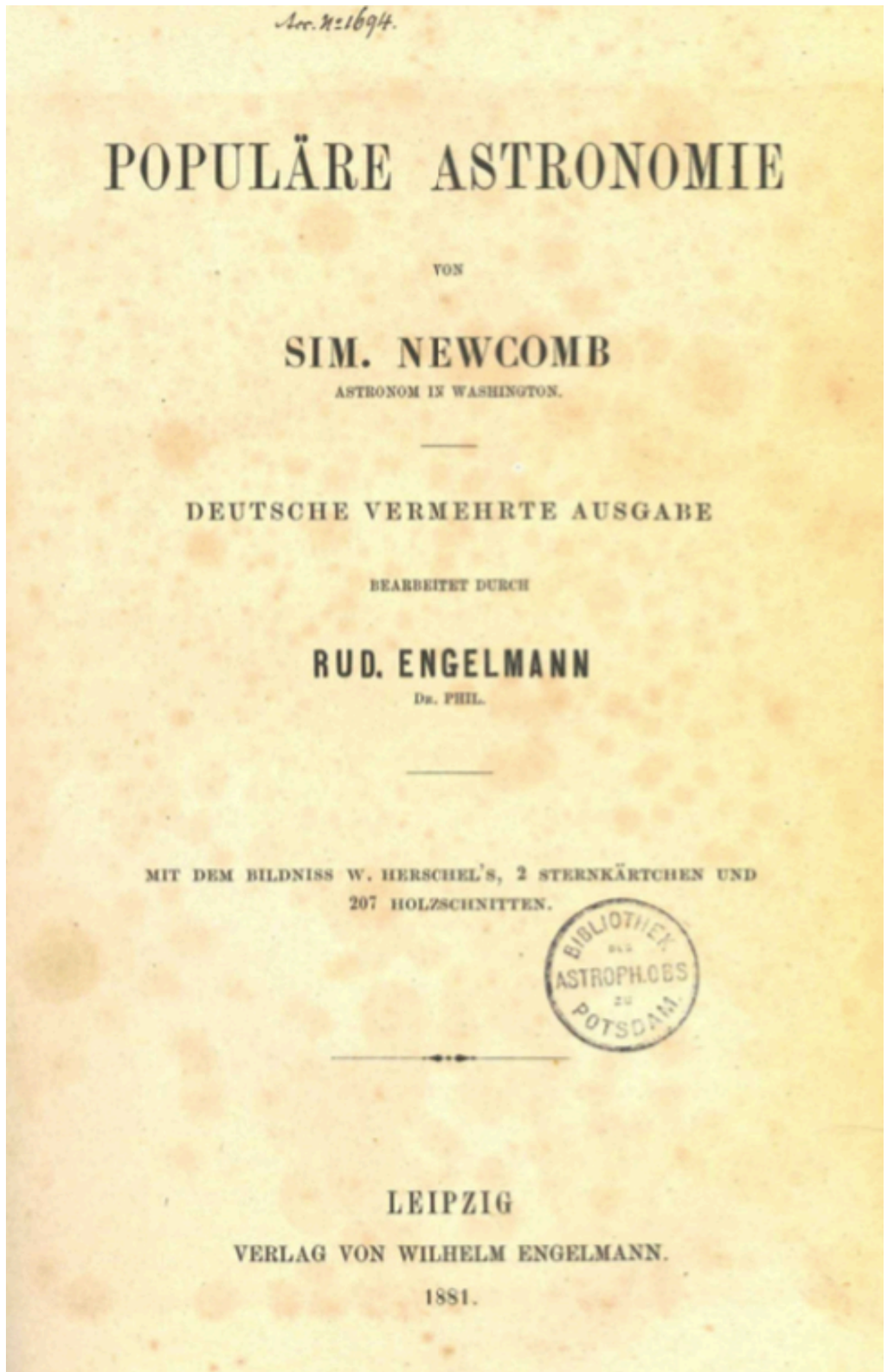
- No mention of d'Arrest
- Map is crucial
- planet recognised as a disk
- Edition of 1883 has the same text



Populäre Astronomie

"Le Verrier wrote to Galle in Berlin and **asked him to look** for the planet based on the **just finished** page of the 21h in the **academic star chart**. Galle, **assisted by d'Arrest**, found on the same evening, the 23rd of September, an object missing from the new map, which contained much fainter stars, and showing a **planet-like disk** with greater magnification. The following night clearly showed the movement of the suspicious star, and so was Neptune, the new planet, discovered barely 1 degree from the places theoretically predicted by Leverrier." (Newcomb, 1881, page 392)

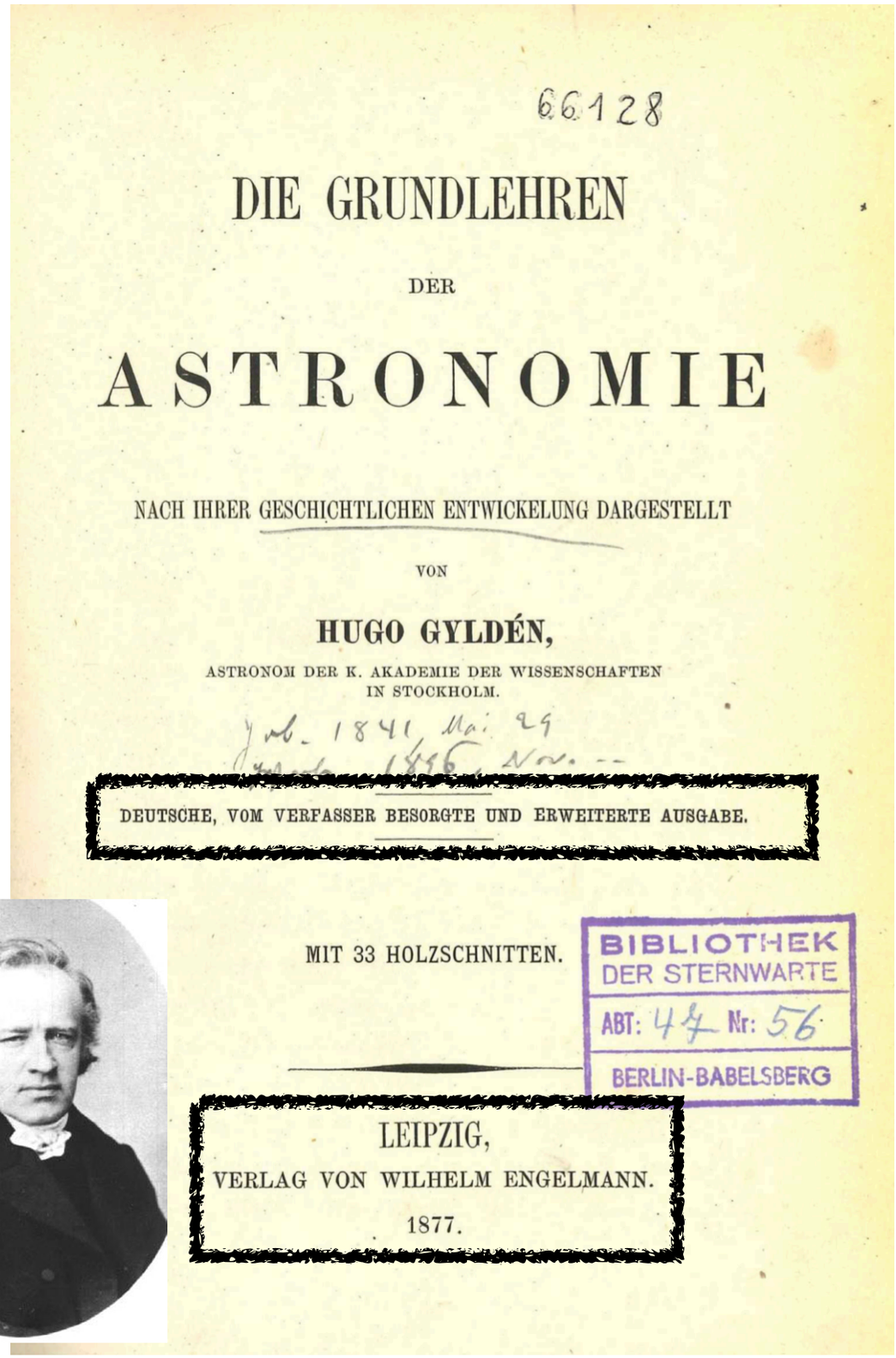
- d'Arrest mentioned (but not Challis)
- Le Verrier asks to look for the planet using the map(!)
- planet recognised as a disk



Who is behind it?

- **Wilhelm Engelmann** (1808-1878)
  - publisher in Leipzig (from a publishing family)
  - after his death, the company continues to publish, led by Christiane Therese (wife) and Rudolf (son)

- **Rudolf Engelmann** (1841 - 1888)
  - publisher
  - astronom (1863 - 1878)
    - assistant of Karl Christian Bruhns (Encke's student)
- **1848 - 1857**: **d'Arrest** works in Leipzig
  - assistant, then professor
  - did d'Arrest spread the rumours about the discovery night?



Correct version of the events?

- **1877 Johann Gottfried Galle, AN, 89, 349**
  - the first complete description of the discovery night by a participant (all others are dead!)
  - direct response to Gylden's book (and perhaps Dreyer's obituary)
  - prominent role of d'Arrest
- **1882, Johann Gottfried Galle, AN, 101, 219**
  - reply to the text in "Populäre Astronomie" and the usage of the map
  - Le Verrier didn't know about the map, wrote to me because of my PhD dissertation
- **1882, John Dreyer, Copernicus, 2 , 63**
  - points out that d'Arrest thought of the map first (this is already in Galle's 1877 text)
  - tells the story how he (Dreyer) got to now the story of the discovery:
    - observed with d'Arrest
- **1882, Galle, Copernicus, 2, 96**
  - reply to Dreyer's text

On the night of June 14, 1874, while observing Coggia's comet together, I reminded Professor d'Arrest, how he had once said in the course of a lecture, that he had been present at the finding of Neptune and that "he might say it would not have been found without him." He then told me (and I wrote it down the next day), how he had suggested the use of Bremiker's map (as first mentioned by Dr. Galle in 1877) and continued: "We then went back to the dome, where there was a kind of desk, at which I placed myself with the map, while Galle, looking through the refractor, described the configurations of the stars he saw. I followed them on the map one by one, until he said: and then there is a star of the 8th magnitude in such and such a position, whereupon I immediately exclaimed: that star is not on the map!"

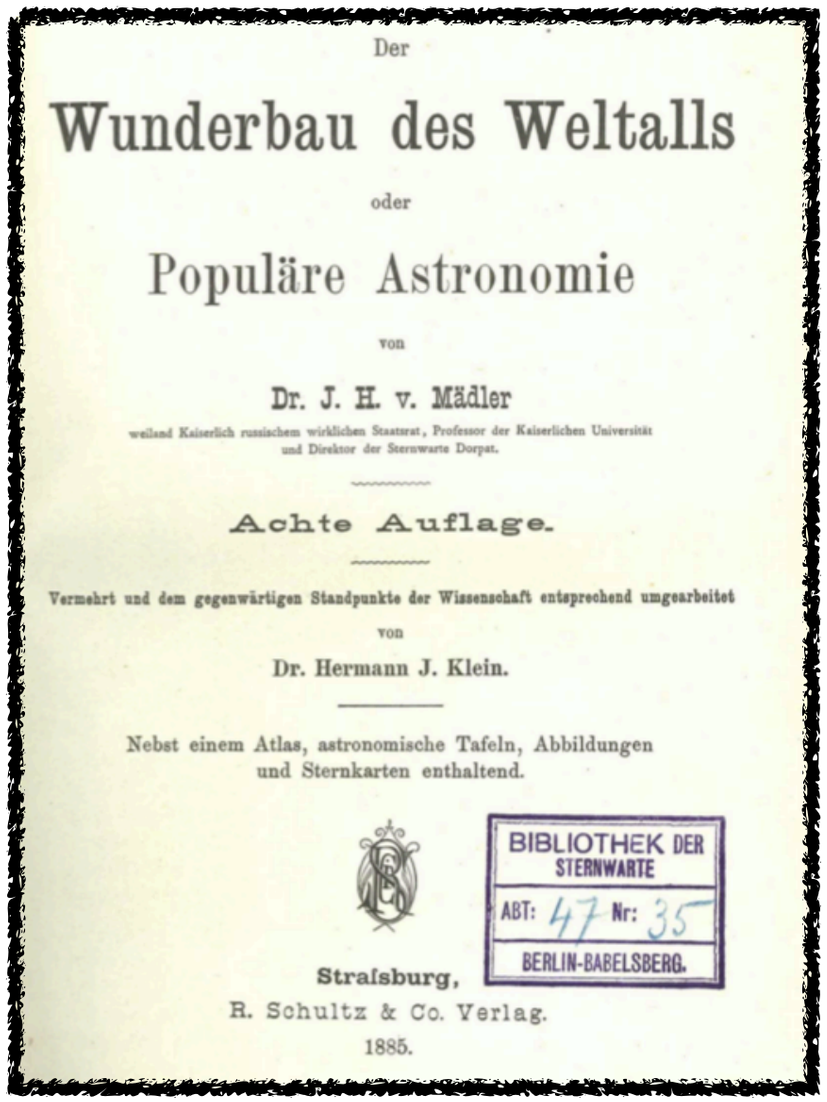
That d'Arrest thus not only first thought of looking for a map (without which the search might have proceeded as slowly as the operations at the Cambridge Observatory did), but actually *took part in the observation*, does not appear to be without historical interest, and it seems only just to that afterwards distinguished astronomer to say that Neptune was found by Galle and him, observing together.

In the meantime d'Arrest, hearing this, expressed the implicit wish to be allowed to participate in the observation. Although **it was not my intention to relinquish this search** and the possibility of an eventual observational success to another observer, such thoughts were remote and it would have seemed unkind to me, to in some way reject the wish of this young zealous astronomer, so **I gladly gave my consent to the attendance**. The same had, therefore, helped with **writing down, looking up at the map**, and perhaps a few other tasks, which I have no particular recollection of, which, however, as does not need to be discussed further, could have been carried out by me without a considerable loss of time, and while being personally appreciated, they **were objectively irrelevant**. On the other hand, I have always considered, as a significant contribution to a faster exploration of the planet, **d'Arrest's quick memory of the academic maps**, although here, too, opinions may and may have differed, to what extent it was inevitable and necessary for me to remember the academic maps. *(Galle, 1882)*

Rumours vs truth

Rumor	Verdict	Fact
d'Arrest calculate the position on the sky	✓	Galle tasks d'Arrest with conversion of Le Verrier's coordinates to sky coordinates
d'Arrest prepares observations	✓	d'Arrest prepares observations
D'Arrest prepares Hora XXI	✗	d'Arrest suggest to check if there is a map, after unsuccessful search for a disk
Galle joins in, looks through the telescope and finds the planet	✗	Galle is leading the observations (and in charge)
Le Verrier writes because he knew there is a map in Berlin	✗	Schumacher's idea + Galle's PhD thesis
Galle observes, d'Arrest checks the map	✓	"That star is not on the map"

Omissions of d'Arrest



Der

Wunderbau des Weltalls

oder

Populäre Astronomie

von

Dr. J. H. v. Mädler

weiland Kaiserlich russischem wirklichen Staatsrat, Professor der Kaiserlichen Universität und Direktor der Sternwarte Dorpat.

Achte Auflage.

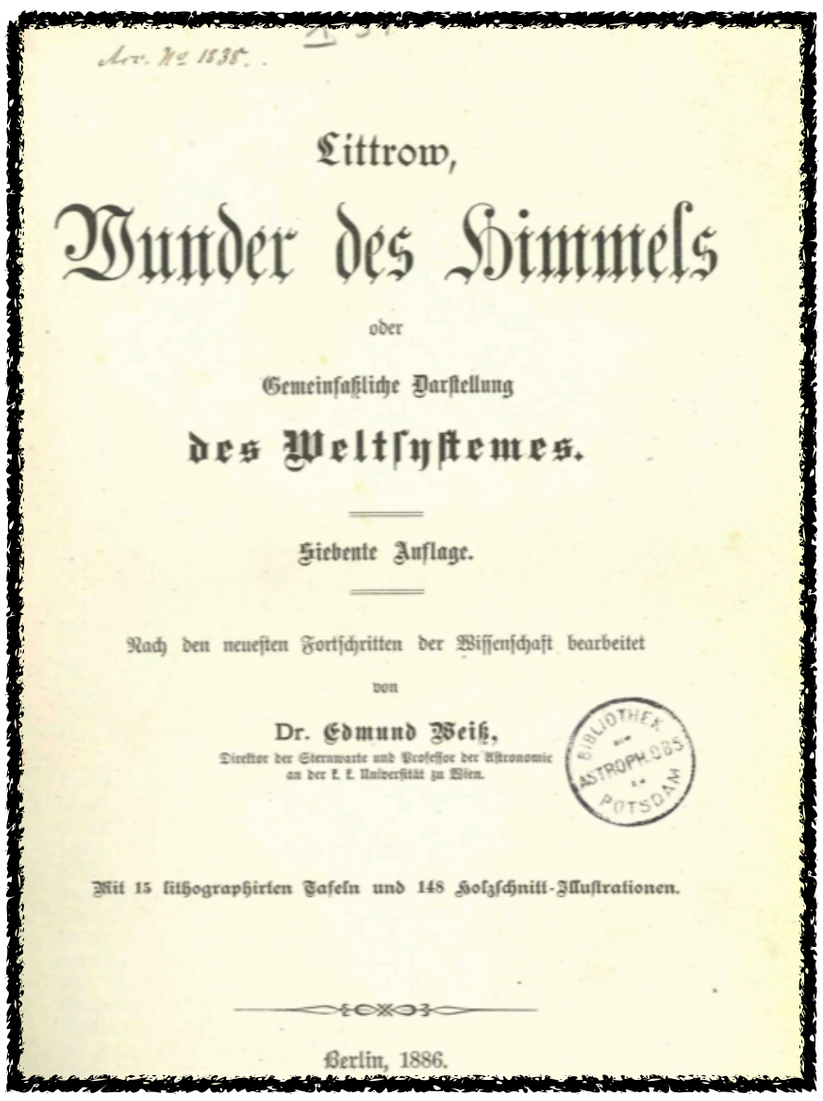
Vermehrt und dem gegenwärtigen Standpunkte der Wissenschaft entsprechend umgearbeitet

von

Dr. Hermann J. Klein.

Nebst einem Atlas, astronomische Tafeln, Abbildungen und Sternkarten enthaltend.

Strafsburg,
R. Schultz & Co. Verlag.
1885.



Littrow,

Wunder des Himmels

oder

Gemeinfaßliche Darstellung

des Weltſyſtemes.

Siebente Auflage.

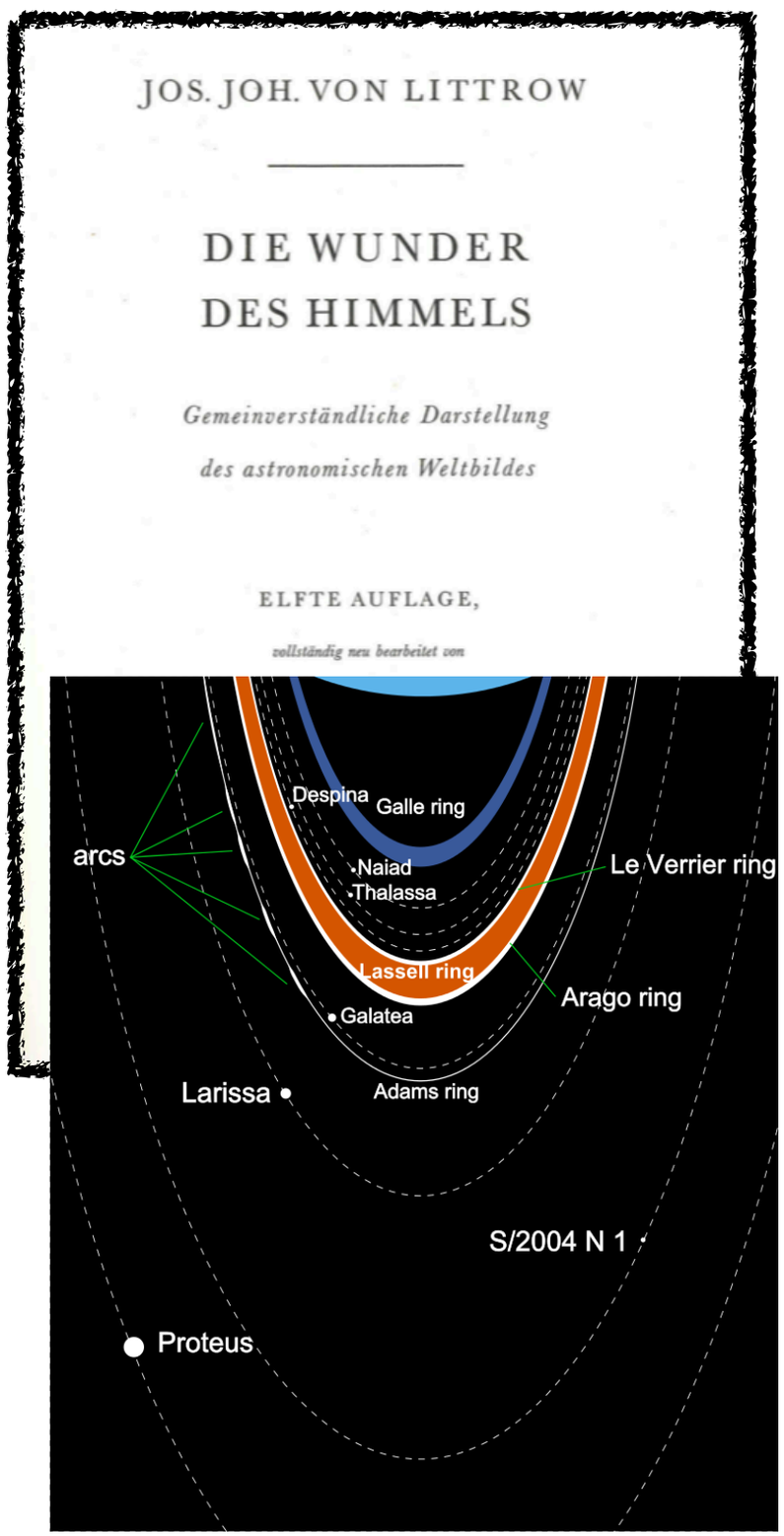
Nach den neueſten Fortſchritten der Wiſſenſchaft bearbeitet

von

Dr. Edmund Weiß,
Direktor der Sternwarte und Profeſſor der Aſtronomie an der k. k. Univerſität zu Wien.

Mit 15 lithographirten Tafeln und 148 Holzſchnitt-Illuſtrationen.

Berlin, 1886.

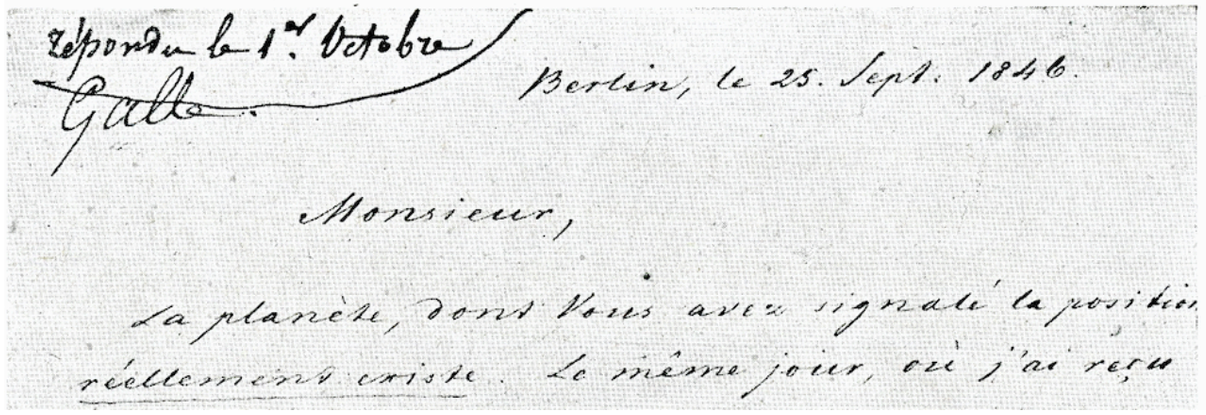


- These works **only mention Galle and Bremiker's map** - they follow what is written in the official publications (often verbatim)
- 1885, 1886, 1969(!); continues still: e.g. Dunkely, J, "Our Universe" (2019, HUP)
- Dreyer might have started the avalanche, but (my feeling is that) it was **Galle** that **made sure** that at least one popular astronomy book has **d'Arrest's name** correctly **associated with the discovery**

Name of the planet
or
Gossips for the end

The Name Game

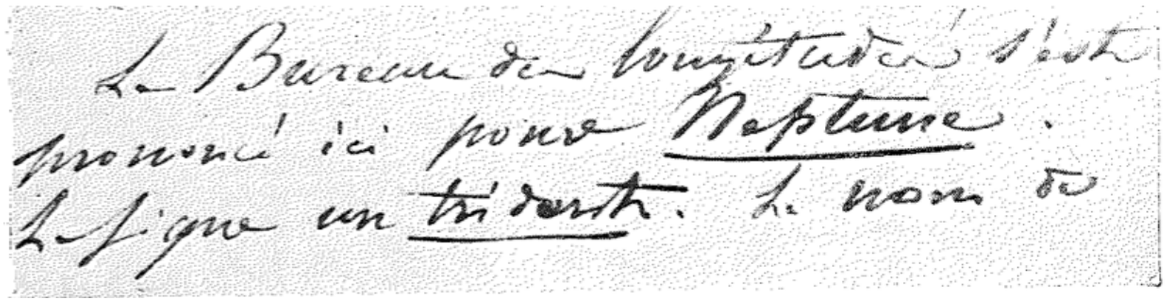
- The usual praxis: the **discoverer proposes the name**, astronomical **community confirms it**
    - Herschel and Piazzi not successful
- **Galle to Le Verrier** (25. September 1846): "This planet might be worth of being called **Janus**, one of the most ancient deities of the Romans, whose two-sided face would signify its position at the frontier of the Solar System"
- **Le Verrier to Galle** (1 October 1846): " **The Board of Longitudes** here has **proposed** the name of **Neptune**, with a **trident as symbol**. The name Janus would mean that this planet is the last of the Solar System, something that there is no reason to believe"
    - "Neptune" is reported by the newspapers in France and in England (based on initial report of Le Verrier)
    - Germany: "**So lass den Namen Neptun sein**" (Holland, 1872)
- Challis and Adams: "**Oceanus**" (17. October 1846)
- Arago: "**Le Verrier**" (19. October 1846)
    - **proposes a deal**: Neptune --> Le Verrier, Uranus (the Georgian)--> Herschel
    - Le Verrier himself adopts "Le Verrier" as the name

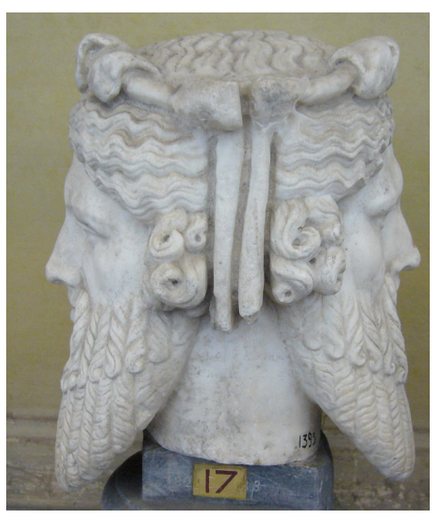

répondu le 1er Octobre
Galle.

Berlin, le 25. Sept. 1846.

Monsieur,

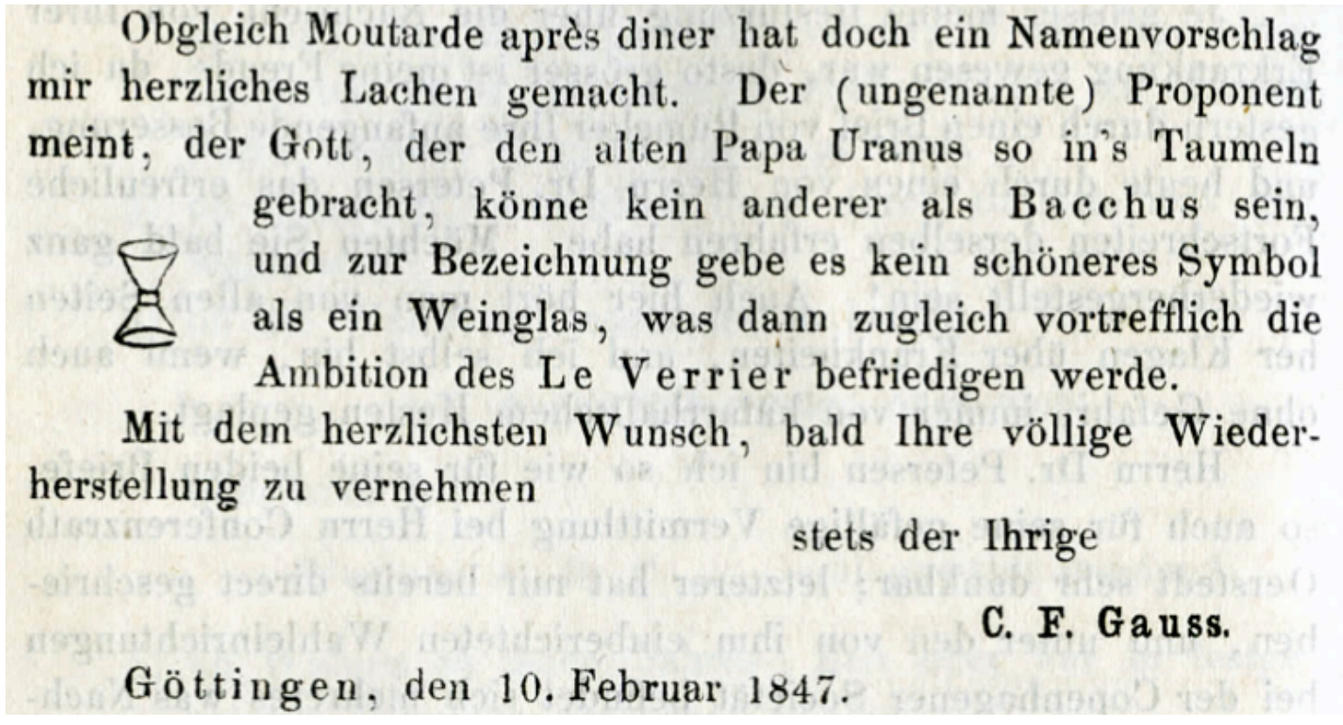
La planète, dont Vous avez signalé la position
réellement existe. Le même jour, où j'ai reçu


Le Bureau des longitudes a fait
proposé ici pour Neptune.
Le signe un trident. Le nom de



Gauss and Schumacher at a Possenspiel

- Le Verrier "gave" the right to François Arago to name the planet
  - Arago decided on "Le Verrier"
- Gauss:
  - name Neptun is "**schicklich**"
  - "**I will hardly ever use the name Le Verrier because I find it improper**" (Gauss to Schumacher, 31 Oct. 1846)
  - "**Adams - Leverrier'schen Planet**" (Gauss to Schumacher 18 Dec 1846)
  - "I can only consider the entire later comedy like a Possenspiel [a farce]. It means to take astronomers as fools, if you ask them today what name you want to choose, say Neptune, I give my approval in advance and tomorrow: No, it should have my name." (Gauss to Schumacher 18 Dec 1846)
- Schumacher:
  - discusses the "**legality**" of Arago's action
    - it looks OK as, Le Verrier "gave his permission and was present"
    - but was it "**forced**" by Arago on Le Verrier
- Other ideas:
  - A. Humboldt:"**Erbus**" ("Poseidon")
  - Encke: "**Vulcan**"
  - many: "**Le Verrier's planet**"
  - John Herschel: "**Minerva", "Hyperion"**



Obgleich Moutarde après diner hat doch ein Namenvorschlag mir herzliches Lachen gemacht. Der (ungenannte) Proponent meint, der Gott, der den alten Papa Uranus so in's Taumeln gebracht, könne kein anderer als Bacchus sein, und zur Bezeichnung gebe es kein schöneres Symbol als ein Weinglas, was dann zugleich vortrefflich die Ambition des Le Verrier befriedigen werde.

Mit dem herzlichsten Wunsch, bald Ihre völlige Wiederherstellung zu vernehmen

stets der Ihrige

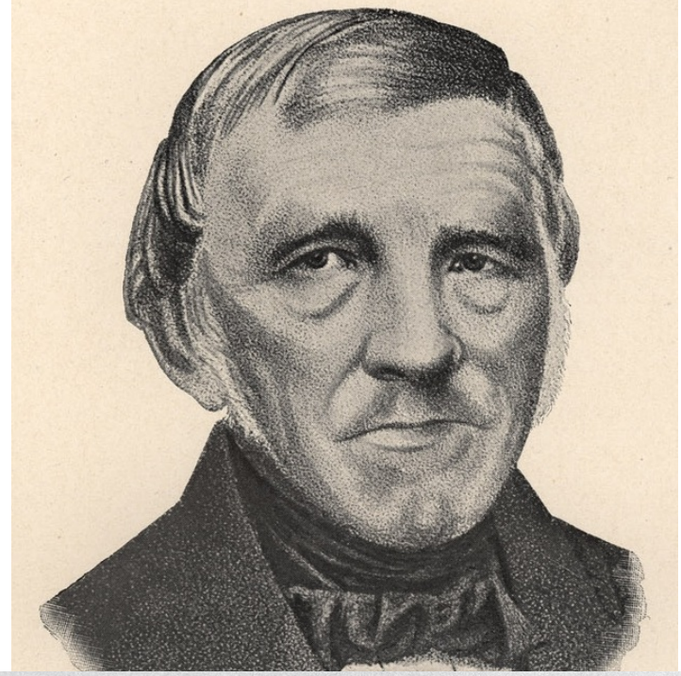
C. F. Gauss.

Göttingen, den 10. Februar 1847.

The German Decision

- **Schumacher to Airy**: "My German friends find Arago's arrogance intolerable" (18 Dec 1846)
- **Encke** to Berlin Academy, **Wilhelm Struve** to St. Petersburg Academy (and a letter to Airy)
  - we will use **Neptune** in observatory **almanacs**?
- **Encke's reasons**:
  - all planets have **mythological names**
  - **Board of Longitude** has proposed Neptune
  - "unserer ersten deutschen astronomischen Autorität" **Gauss wrote**: "I find the name Neptune chosen by Mr. Le Verrier perfectly decent: as a sign one could perhaps choose a trident, if it were not inappropriate to anticipate the author in any way"
- **Struve's reasons**:
  - **mythological names**, even Uranus was accepted by John Herschel
  - **Board of Longitude** has proposed Neptune
  - **John Couch Adams** also **predicted** the location of the planet
- Airy published Struve's letter (The Athenaeum, 20. Feb. 1847)

Franz Johann Encke (1791-1865)



Friedrich Georg Wilhelm Struve (1793-1864)

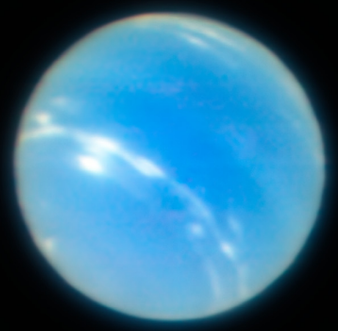
Neptune

"I don't quite like this proposed change in the nomenclature of the Planets, for mythology is neutral ground. Herschel is a good name enough. Le Verrier somehow or other suggests the idea of a Fabriquant & is therefore not so good. But just think how awkward it would be if the next planet should be discovered by a German: by a Bugge, a Funk, or your hirsute friend Boguslawski!" (W.H. Smyth to Airy 5 Dec 1846)

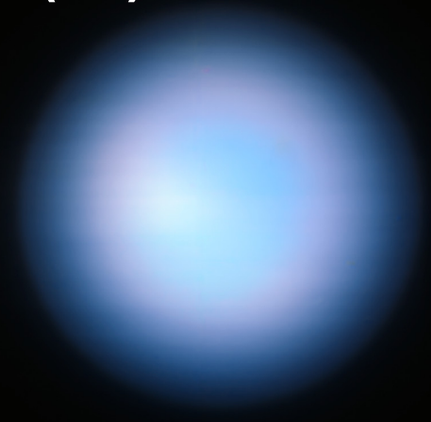
William Henry Smyth (1788 - 1965)

Date	Planet	Discoverer	Place
13 March 1781	Uranus	W. Herschel	Bath
1 January 1801 (31 December 1801)	Ceres	G. Piazzi (Gauss, Olbers)	Naples (Bremen)
28 March 1802	Pallas	H.W.M. Olbers	Bremen
1 September 1804	Juno	K. Harding	Lilienthal
29 March 1807	Vesta	H.W.M. Olbers	Bremen
8 December 1845	Astraea	K.L. Hencke	Driessen
23 September 1846	Neptnue	J.G. Galle, H.L. d'Arrest (Le Verrier)	Berlin (Paris)

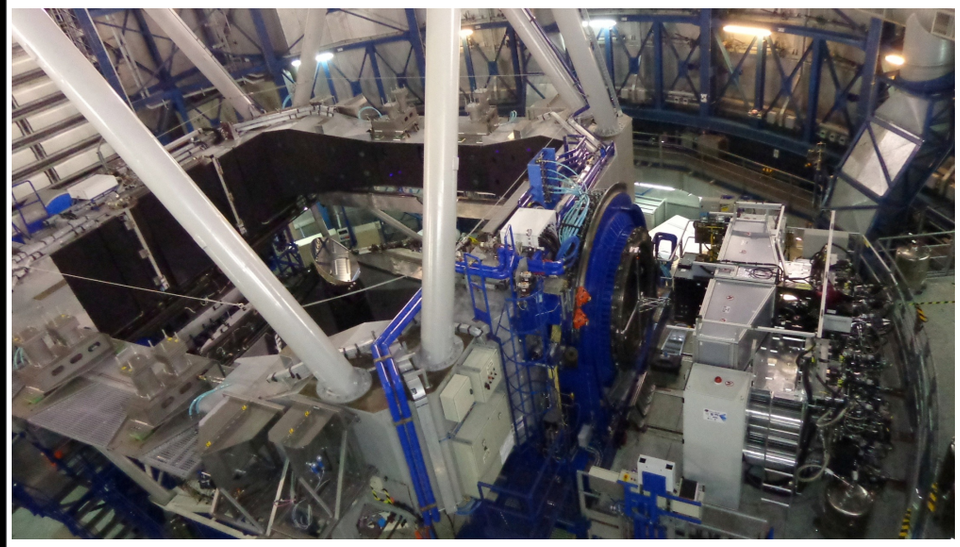
European Southern Observatory
Very Large Telescope (8m)
MUSE

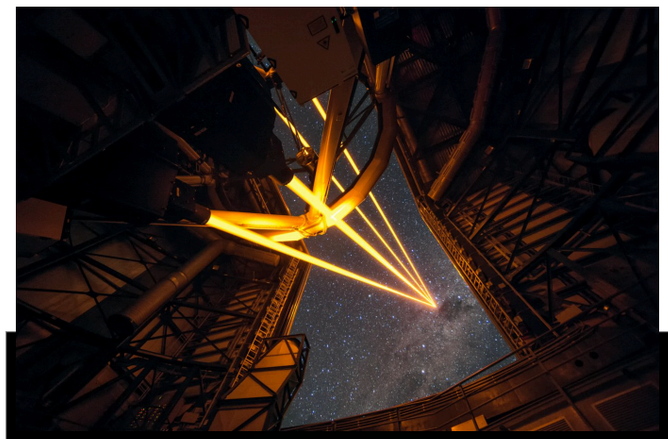


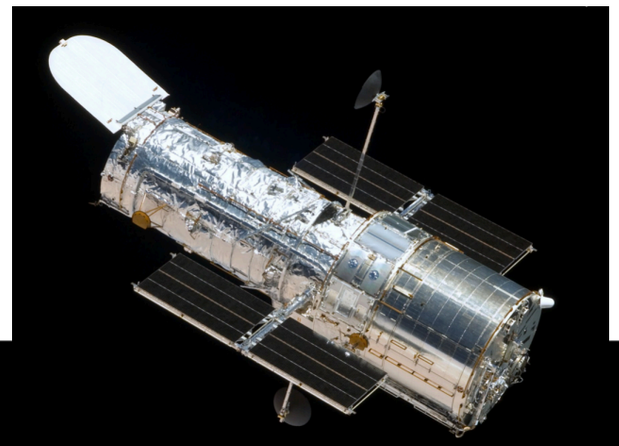
Adaptive optics

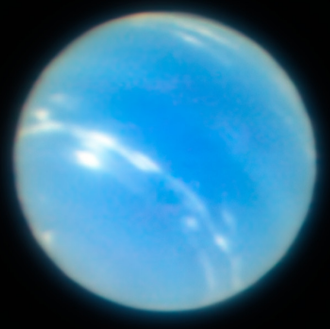


No Adaptive optics

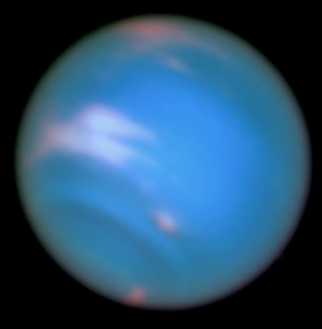








VLT Adaptive Optics



Hubble Space Telescope