

The discovery of Neptune

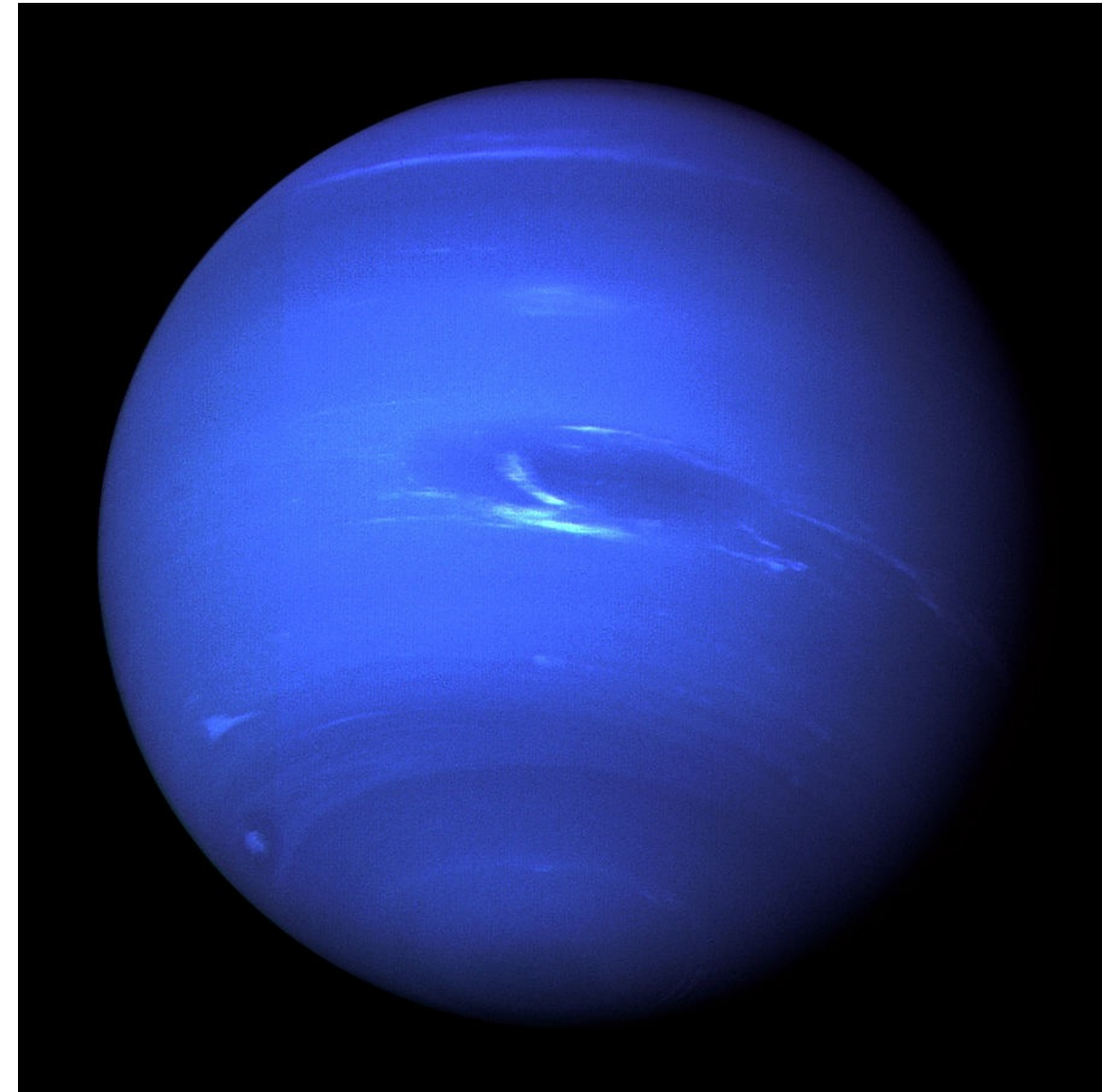
Dramatis personae

Act 1. Setting the Scene

Davor Krajnović
Kaffeerunde (01.06.2016)

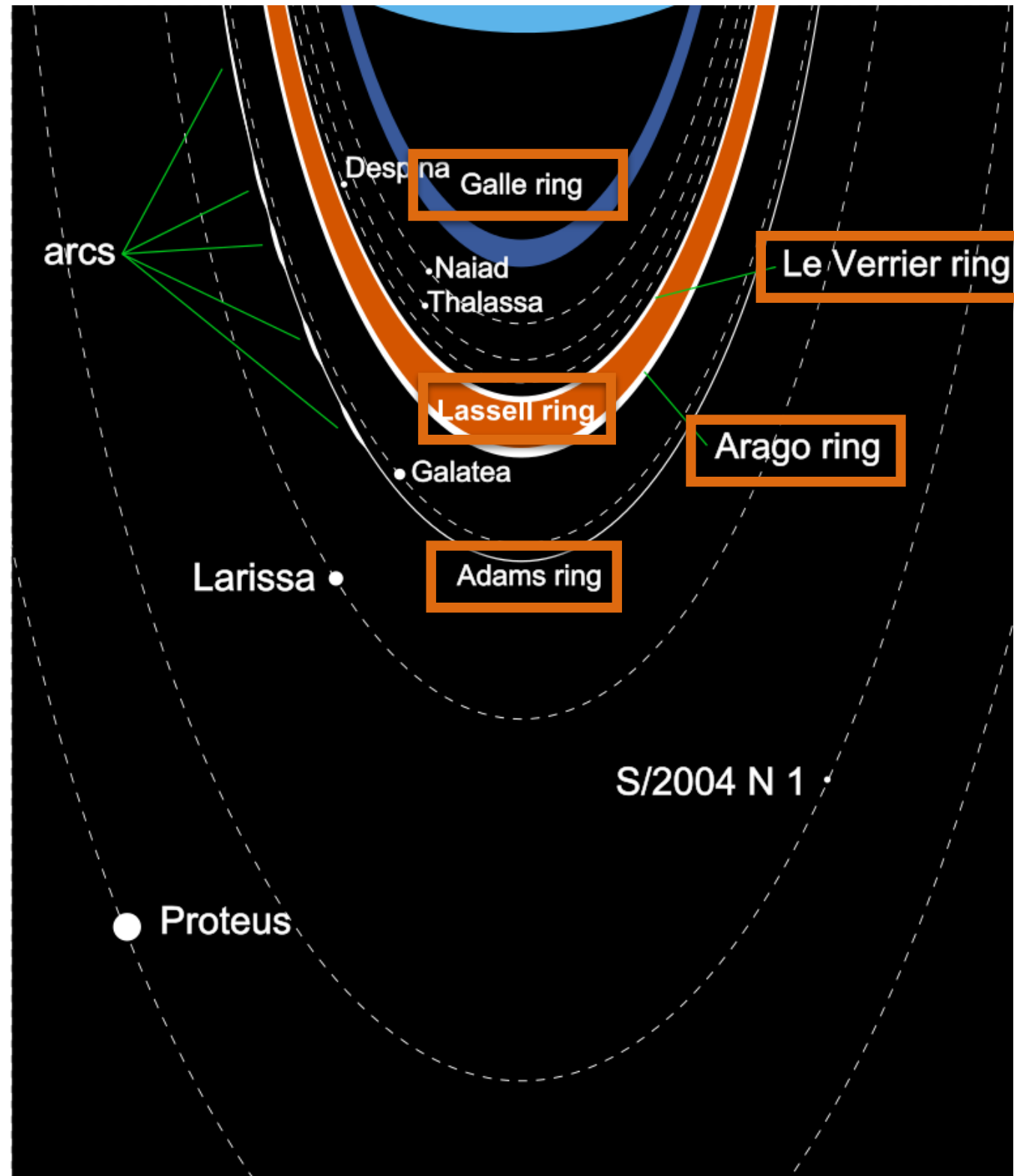
A most fascinating story

- 23.09.1846, a letter (dated 18.09.) arrives to Berlin Observatory, addressed to **Johann Gottfried Galle** from **Urbain Jean Josphe Leverrier** with a prediction where an *yet unseen* planet should be on the sky
- the same night, Galle together with **Heinrich Louis d'Arrest**, with a help of a newly made chart of that part of sky (by **Carl Bremiker**) discover Neptune
- the world is astonished
 - new body in the solar system
 - predicted by theory of perturbation (anomalous motion of Uranus)
 - followed by a “bomb” from Britain
- **John Couch Adams** had predicted the location of Neptune one year before (September 1845), and **James Challis** (Cambridge Observatory) was set by **George Biddell Airy** to search for it since July 1846



A most fascinating story

- educational and entertaining story on at least three levels:
 - the number of people “involved” in the discovery of Neptune is sobering (>100 people mentioned in a book by Grosser)
 - one of early modern scientific cases: one needs solid theory to “see” something new
 - science knows no nationality, but scientists do
- three lectures (focus on people involved)
 - “Setting the scene” (today)
 - “The discovery” (01.07.)
 - “Juicy Parts” (01.09.)



TAG DER OFFENEN TÜR

170 JAHRE NEPTUN-ENTDECKUNG

23. September
16–22 Uhr
Leibniz-Institut für
Astrophysik Potsdam



TAG DER OFFENEN TÜR *170 JAHRE NEPTUN-ENTDECKUNG*

23. SEPTEMBER | 16 –22 UHR
LEIBNIZ-INSTITUT FÜR ASTROPHYSIK POTSDAM

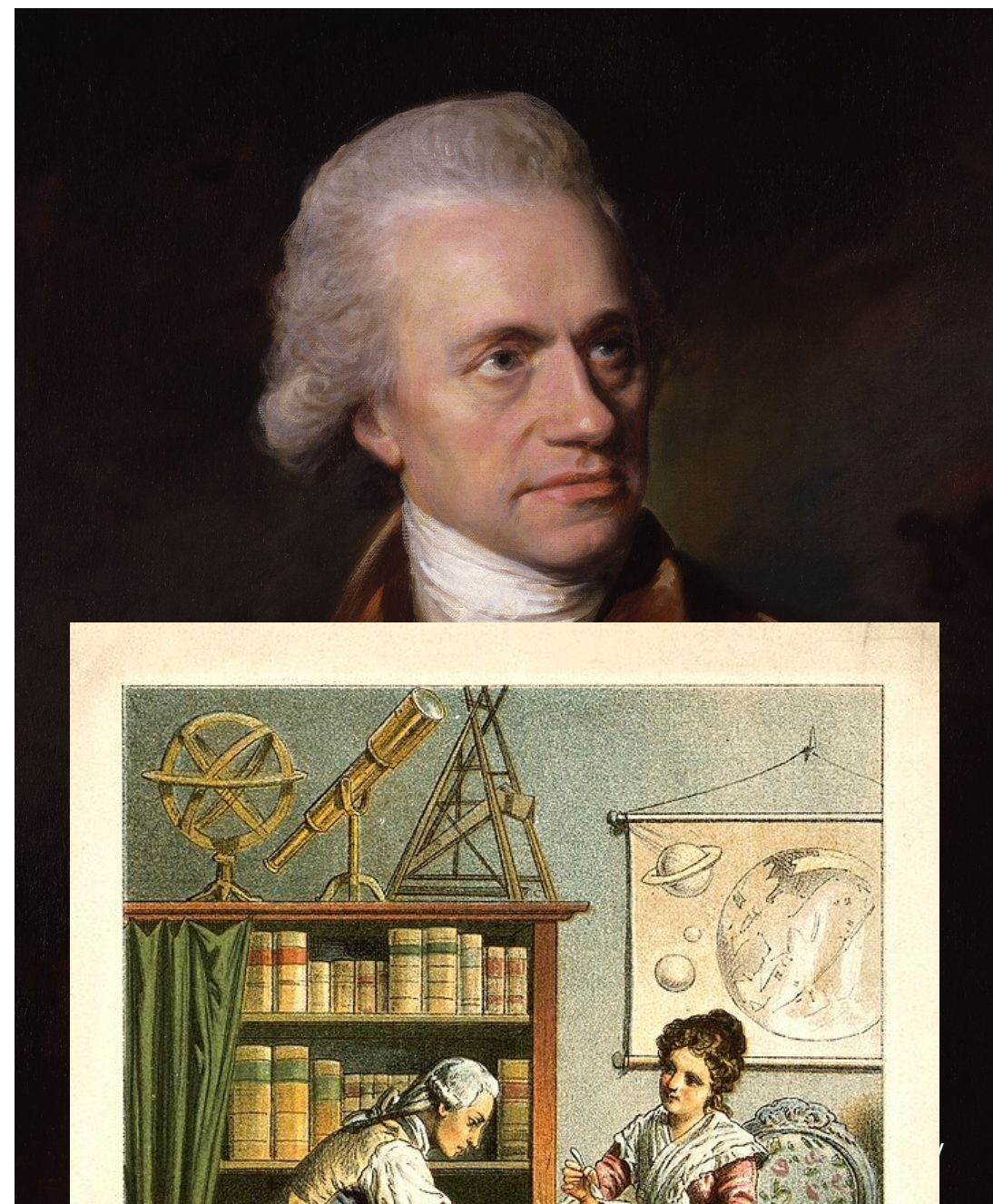
Am Freitag, den 23. September 2016 lädt das Leibniz-Institut für Astrophysik Potsdam (AIP) von 16–22 Uhr zu einem Tag der offenen Tür ein. Anlass ist die Entdeckung des Planeten Neptun vor 170 Jahren. Wissenschaftlerinnen und Wissenschaftler geben Einblicke in die astronomische Forschung mit interessanten Vorträgen, Führungen und Mitmachaktionen für Groß und Klein. Bei klarem Himmel besteht die Möglichkeit zur Beobachtung mit Teleskopen.

Freier Eintritt, keine Anmeldung erforderlich.

Bild: NASA/JPL / Gestaltung: völligohne.de

William Herschel

- **Friedrich Wilhelm Herschel** (1738 - 1822)
- economic migrant to Britain from Electorate of Hannover, set to teach music (1757)
- 1774 constructed 1st telescope
- 13.03.1781 - discovers Uranus with arguably the best telescope in the world (home made by him and his sister Caroline)
- World is astonished and excited
 - new planet: "He broke through the barriers of the heavens"
- telescope builder (40 foot telescope)
- discovered 4 moons (Saturn/Uranus), infrared radiation, suggested MW is a disk, Solar System moves through MW...



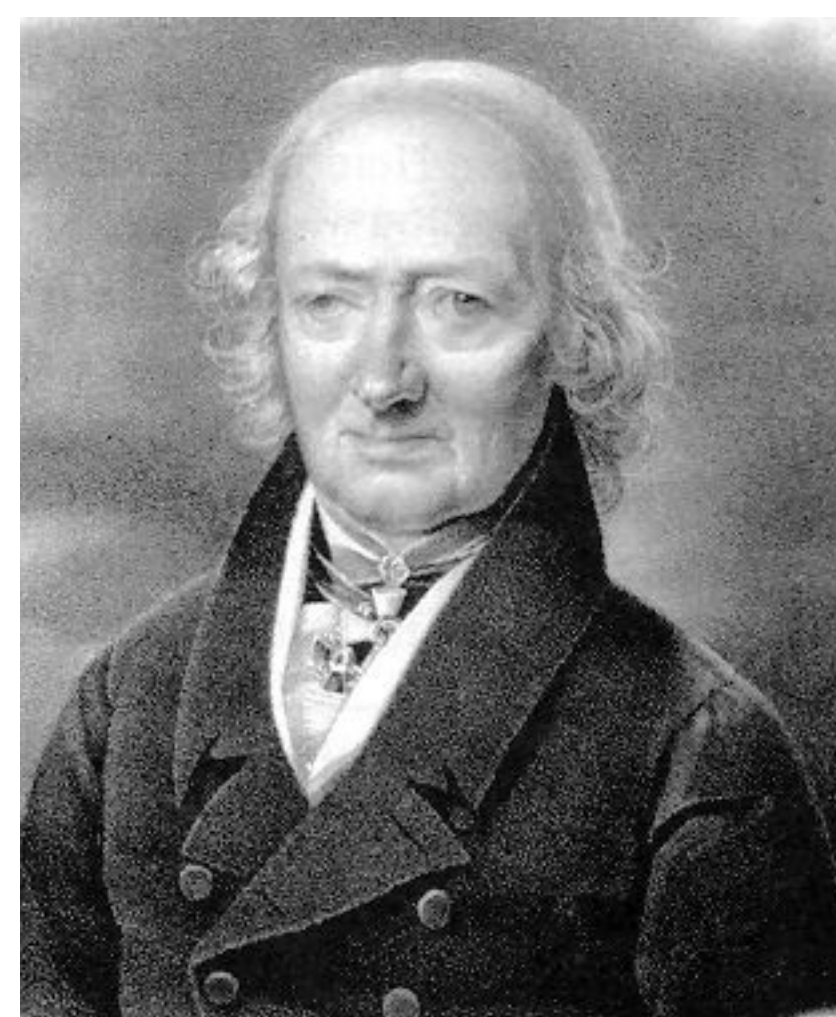
Gr. v. A. Diethe.

T. A. B. XIV.

Caroline Herschel.

Bode and Titius

- **Johann Elert Bode** (1747 - 1826)
- director of Berlin Observatory (1786 - 1825)
- gave name *Uranus* (Herschel suggested "*Georgium Sidus*" - used in Britain; In France the planet was known as "*Herschel*")
- discovered old ("ancient") observations of Uranus
- famous for: "Titius - Bode law/rule"
 - evangelical conviction this is an important law
- **Johann Daniel Titius** (Tietze) 1729 - 1796)
 - professor in Wittenberg
 - in a translation of "Contemplations de la Nature" by Charles Boinnet, introduced the notion of numerical progression of the planetary distances



Titius - Bode law/rule

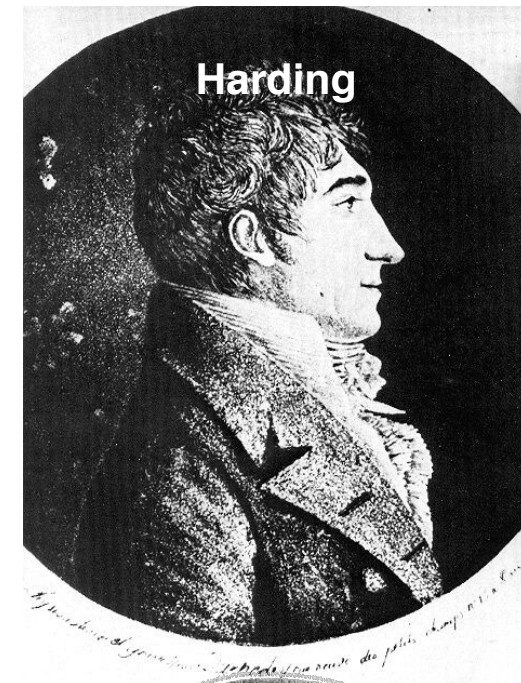
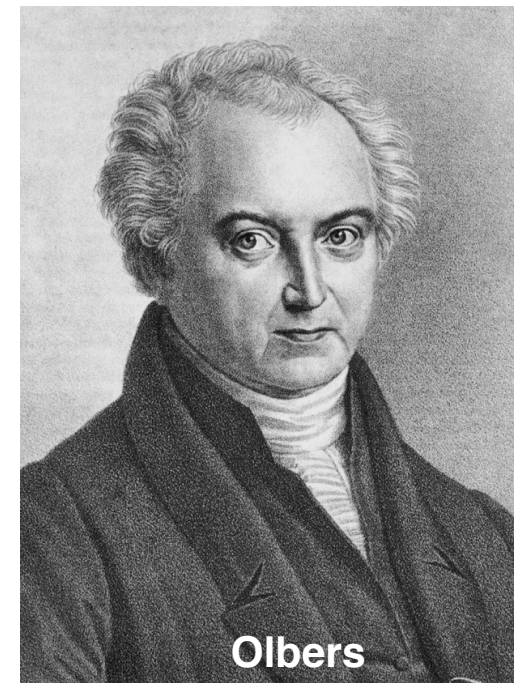
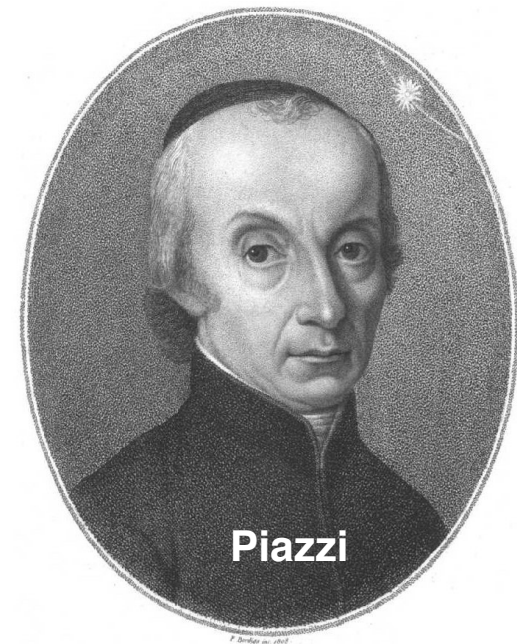
- if Earth distance from the Sun is 10, then other planets have it given by $4+3 \times 2^n$, where $n = -\infty, 0, 1, 2, \dots, 4, 5$
- Uranus was found at $n=6 \Rightarrow 19.2 \text{ AU}!!!$
- after discovery of Ceres (and other asteroids), Titius - Bode law went from a curiosity to main stream respectability (and crucial for the discovery of Neptune!)

k	T-B rule distance (AU)	Planet	Semimajor axis (AU)	Deviation from prediction ¹
0	0.4	Mercury	0.39	-3.23%
1	0.7	Venus	0.72	+3.33%
2	1.0	Earth	1.00	0.00%
4	1.6	Mars	1.52	-4.77%
8	2.8	Ceres ²	2.77	-1.16%
16	5.2	Jupiter	5.20	+0.05%
32	10.0	Saturn	9.55	-4.45%
64	19.6	Uranus	19.22	-1.95%

table from Wikipedia with predictions and distances of 1st 7 planets

Piazzi, von Zach and Lilienthal detectives

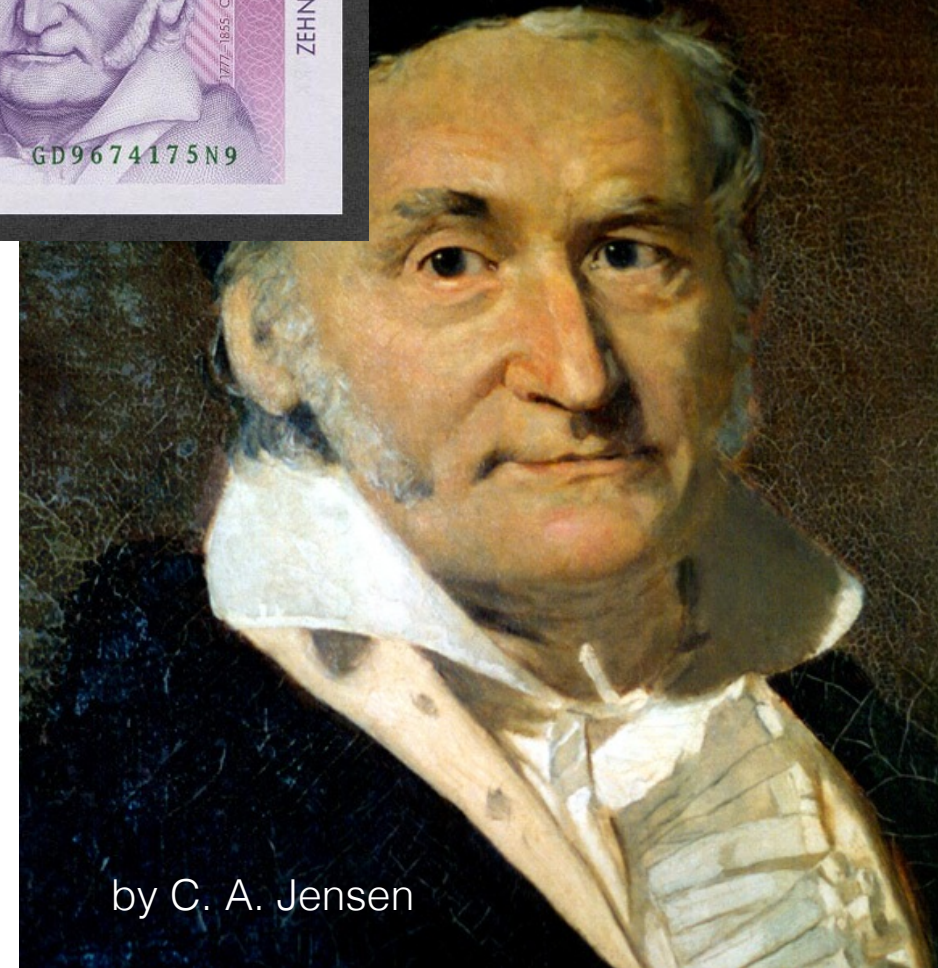
- Baron **Francis Xavier von Zach** (1754 - 1832)
 - Hungarian, worked in Gotha
 - driver behind search for the planet with $n=3$ in Titius - Bode law
- **Giussepe Piazzi** (1746 - 1826)
 - priest in Palermo
 - discovered Ceres (right where it should be according to Titius-Bode rule!) on 01.01.1801.
- **Heinrich Wilhelm Matthias Olbers** (1758 - 1840)
 - devised a method to calculate orbits of comets
 - Olber's paradox
 - discovered Pallas (28.03.1802) and Vesta (29.03.1807)
- **Karl Ludwig Harding** (1765 - 1834)
 - discovered Juno on 02.09.1804. (as an assistant astronomer in a private observatory of **Johann Hyeronimus Schröter** (1745 - 1816), a physician)



Gauss



- Johann Carl Friedrich Gauss (1777-1855)
- mathematical prodigy, professor of astronomy in Göttingen
- Ceres was lost about a month after discovery, and nobody could find it
- several astronomers tried to calculate the orbit and find it (von Zach, Olbers, Bruckhardt)
- Gauss used the known positions and predicted where it will be seen
- 31.12.1801. von Zach found Ceres exactly where Gauss predicted it will be

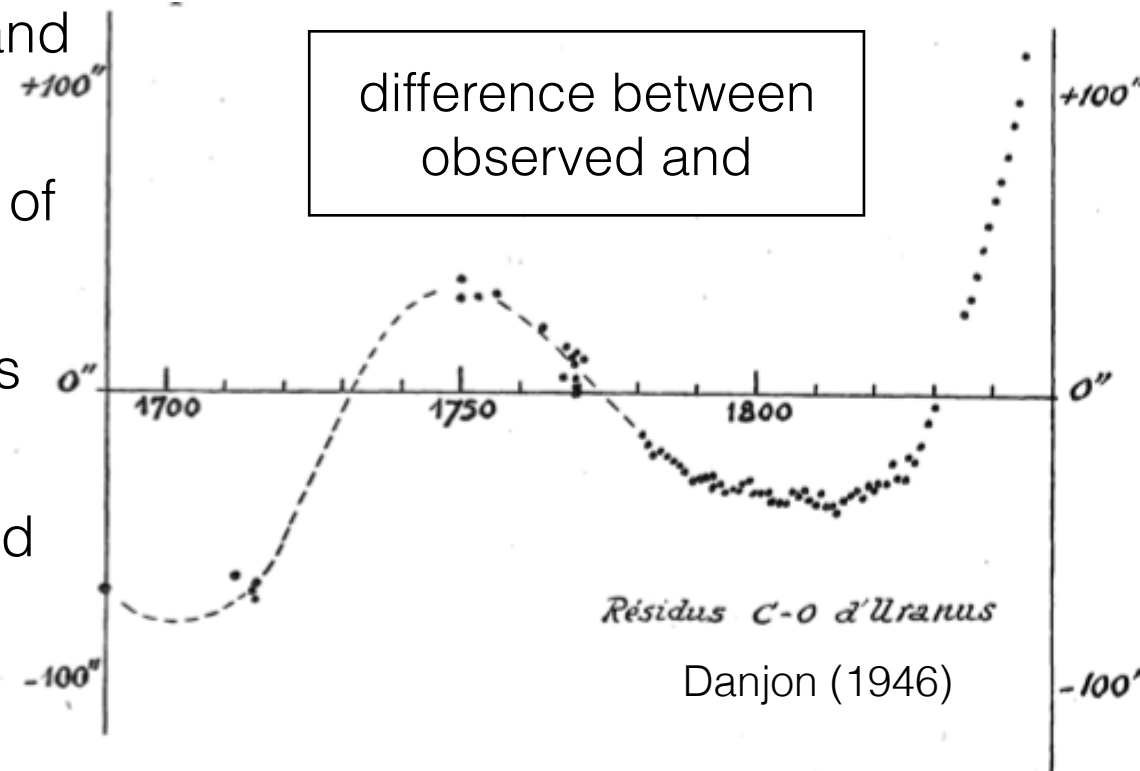


- “*Theoria motus corporum coelestium in sectionibus conicis solem ambientum*”, 1809
- new method of determination of orbits
- least squares method(*)

*Lagrange as well

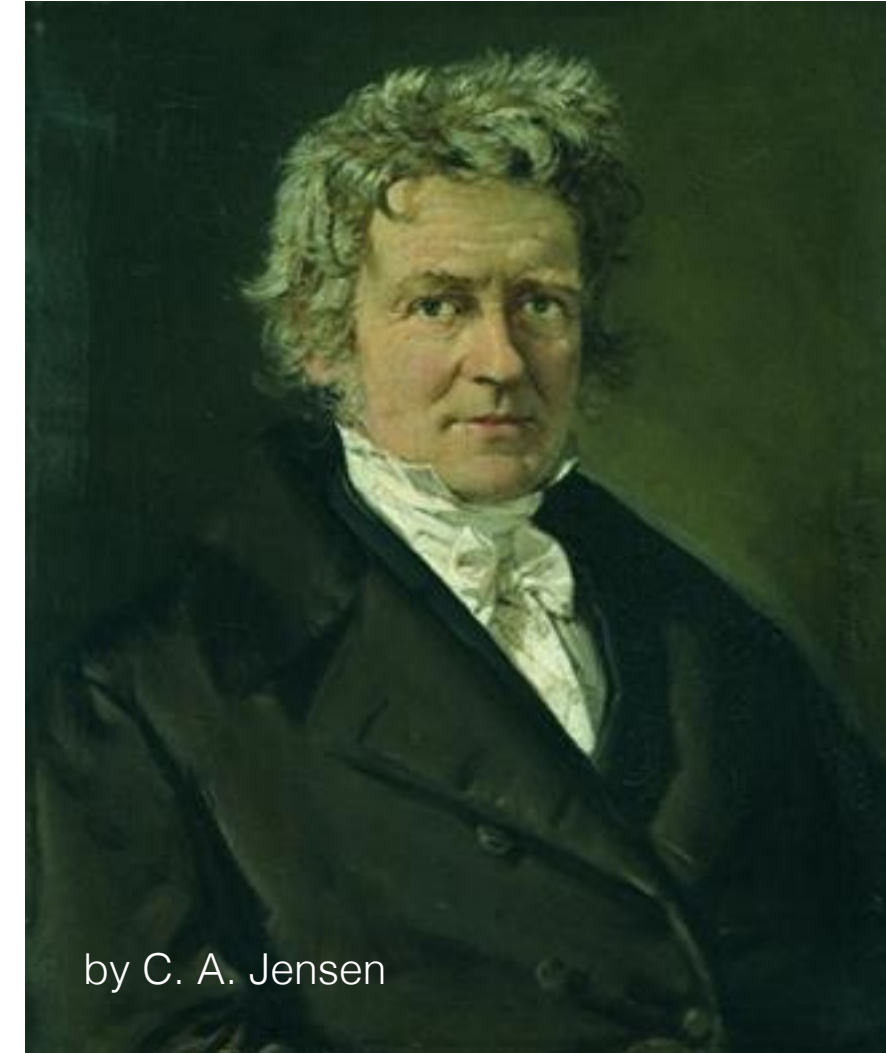
The thing with Uranus

- it was very far: 19.2 AU
- it was observed at least 17 times before 1781 by 4 different observers (Flamsteed, Lemonnier, Bradley, Mayer)
- it took time to determine its orbit (as it was far), but when done, it was a mess!
- **Alexis Bouvard** (1767 - 1843, Director of Paris Observatory) made Tables of Uranus in 1821
- it seemed IMPOSSIBLE to predict where Uranus will be (very different from the cases of other planets including Jupiter and Saturn)
 - allowed uncertainty to the determination of the position of Uranus was $<5''$ in 1820s
 - in 1826, it was typically measured to be $\sim 10''$, but it was decreasing with time, only to start increasing
 - in 1832, George Biddell Airy (more of him later) reported that the errors of the Tables of Uranus are up to $30''$!
- what was going on?



Bessel

- **Friedrich Wilhelm Bessel** (1784 - 1846)
- an apprentice in import-export company in Bremen; improved their business model, but decided astronomy is better
- showed to Olbers his solution to determination of comet trajectories, and left business to assist Schröter at his observatory
- at age of 25 (!) appointed director of Königsberg Observatory (1810)
- 1838 determined the parallax of 61 Cygni (1st parallax!), of 0.314" (9% error compared to present value!), beating Friedrich Georg Wilhelm Struve (Vega - 0.13") and Thomas Henderson (Alpha Centauri - 0.75")
- 1844 predicted there is Sirius B from the motion of Sirius A
- claim on wikipedia: in 1840s convinced Prussian Academy of Sciences to start making Berliner Akademische Sternkarten (you'll see why this was crucial!)



by C. A. Jensen

- 1840 - announced that deviation of Uranus motions are due to an unseen planet (he convinced himself that it is not the law of gravity that has to change)
- 1842 - informed John Herschel that he and his assistant Friedrich Wilhelm Flemming will look for a new planet
- nothing happened —> both died soon after (Bessel after a long sickness)

Mary Somerville



- Mary Fairfax Somerville (1780 - 1872)
- self thought daughter of an admiral (learned Latin to be able to read Newton's *Principia*)
- 1st marriage (to a Captain Samuel Grieg) was luckily short, 2nd (with Dr. William Somerville) “allowed” her to peruse a scientific career
- not a research scientists, but a science synthesiser: wrote books about science, across all sciences
- “gifted and flexible”, able to assimilate new ideas and connect them to a big picture



Laplace told her: “*There have been only three women who have understood me. These are yourself Mrs Somerville, Caroline Herschel and a Mrs Greig of whom I know nothing.*”

Changing attitudes

- Somerville's books on astronomy recored the changing attitudes toward the problem of Uranus
- 1) *Mechanism of the Heavens*, 1831
 - Uranus is the end of the Solar System
- 2) *On the Connexion of the Physical Sciences*, 1st edition 1834
 - no mention of Uranus - it was a mess and it didn't fit in the orders view of science
- 3) *The connexion of the Physical Sciences*, 3rd edition, 1836
 - there must be another massive planet beyond Uranus that does the perturbations