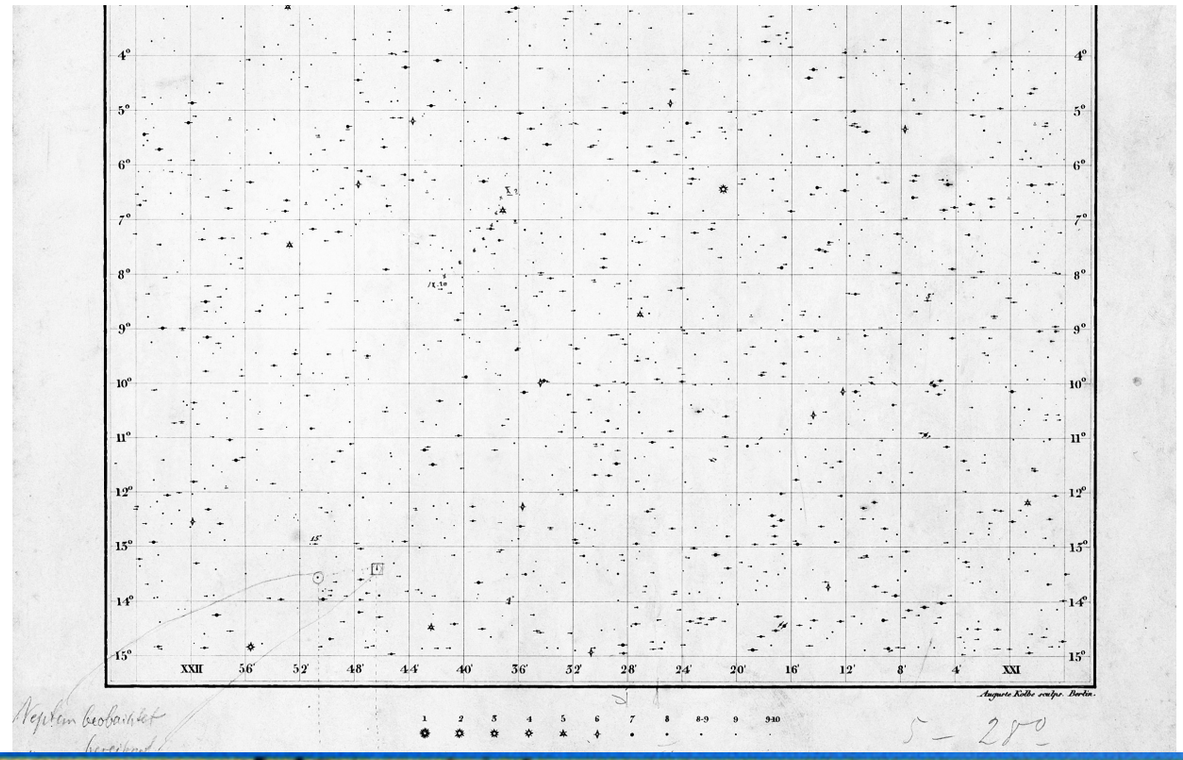
The discovery of Neptune
Dramatis personae

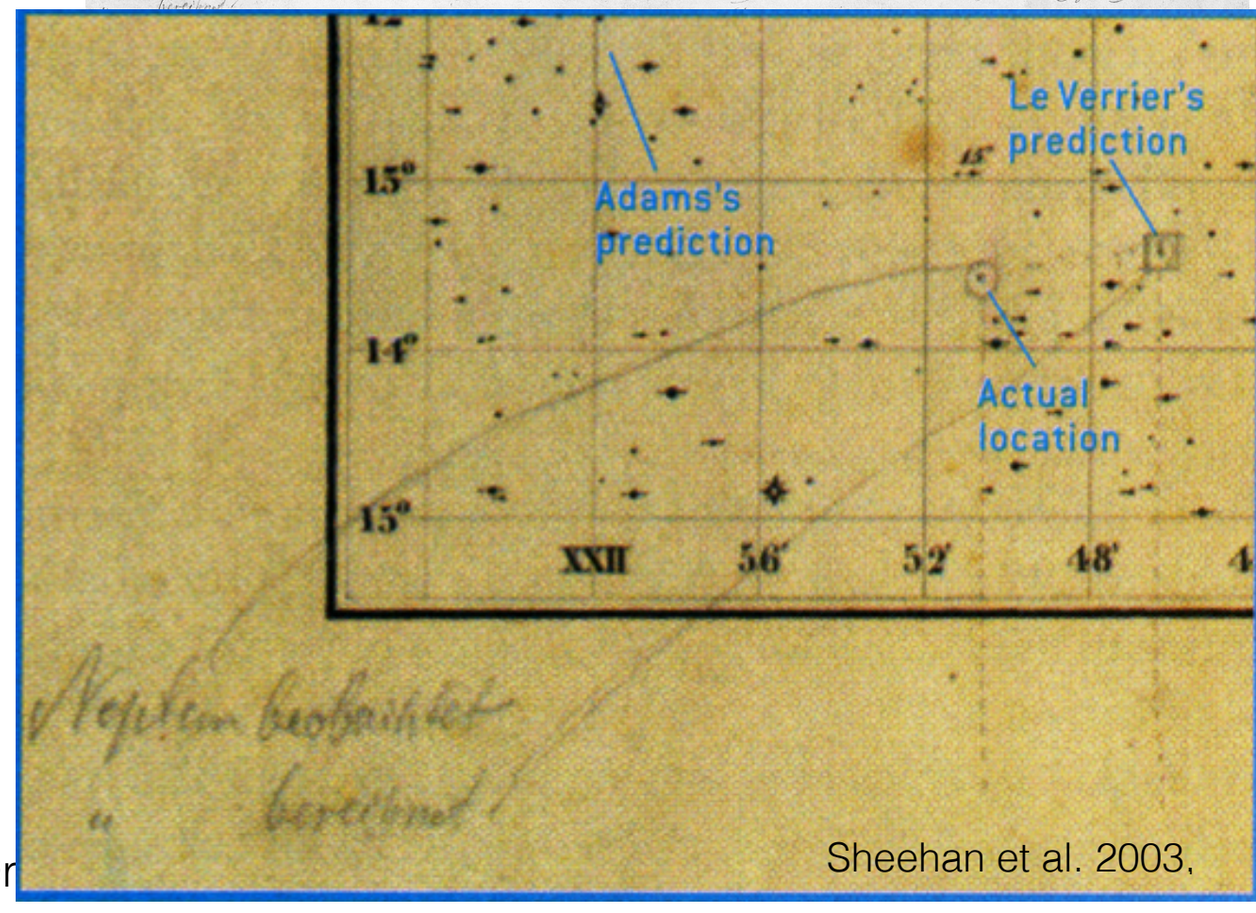
Act 2. The discovery

Davor Krajnović
Kaffeerunde (01.07.2016)

“Le planète, dont vous avez signalé la position, <u>réellement existe</u>”

- 23.09.1846, letter arrives to Galle: why don’t you look for a new planet? It should be the heliocentric longitude of 326 32’ (1.1.1874) and be visible as a disc of >3”!
- it is the director’s (Encke) birthday (there is a party)
- Galle asks the director, if he can search for the planet, Encke agrees (only because there was that letter)
- Heinrich Louis d’Arrest (“student”) asks if he can join
- a clear night
- Galle looks for a disc of 3”, but can’t spot it
- d’Arrest suggest they use a sky map and check if there is a new star
- Galle knows there is a new map in Encke’s office, fresh from the print (almost nobody in Europe has it yet); they go to Encke’s office and take the map from the cabinet
- within 1h (0.5h) they see and 8th mag star that is not on the map! (Galle observes and reads the coordinates of stars, d’Arrest checks on the map)
- Encke is called (party is broken), observations continue till 2:30 am when “the star” sets
- waiting the full day……night of 24.09. is clear
- “the star” has moved!!

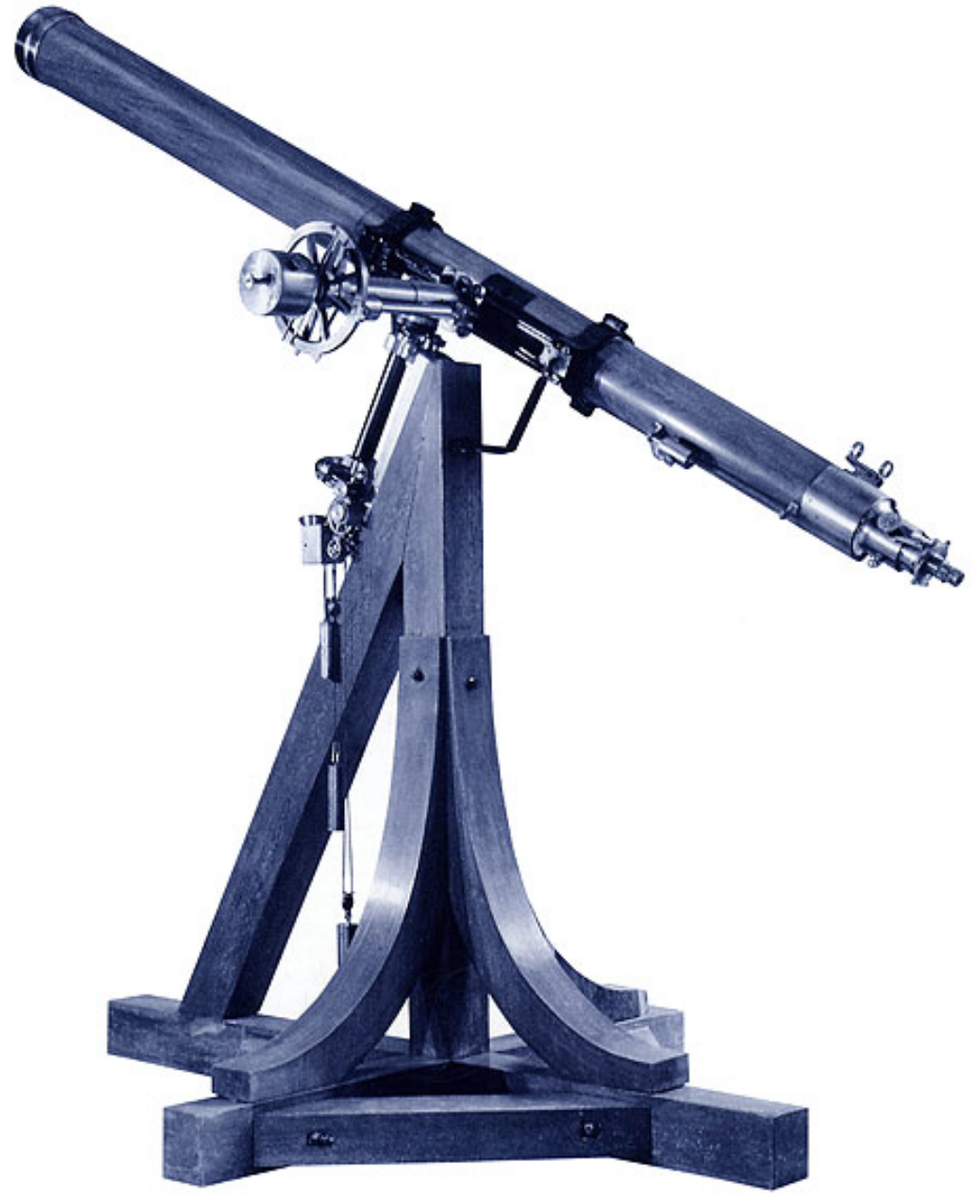




Sheehan et al. 2003,

“Le planète, dont vous avez signalé la position, <u>réellement existe”</u>

- Le Verrier predicted the position: 325^{o} 58’
- Galle found it at: 326^{o} 57’
- Le Verrier predicted size of ~3”
- Encke reported 2.5” (although the measurements were between 2.2” and 3.2”)



Fraunhofer Refraktor of the Berlin Observatory, Deutschen Museum München

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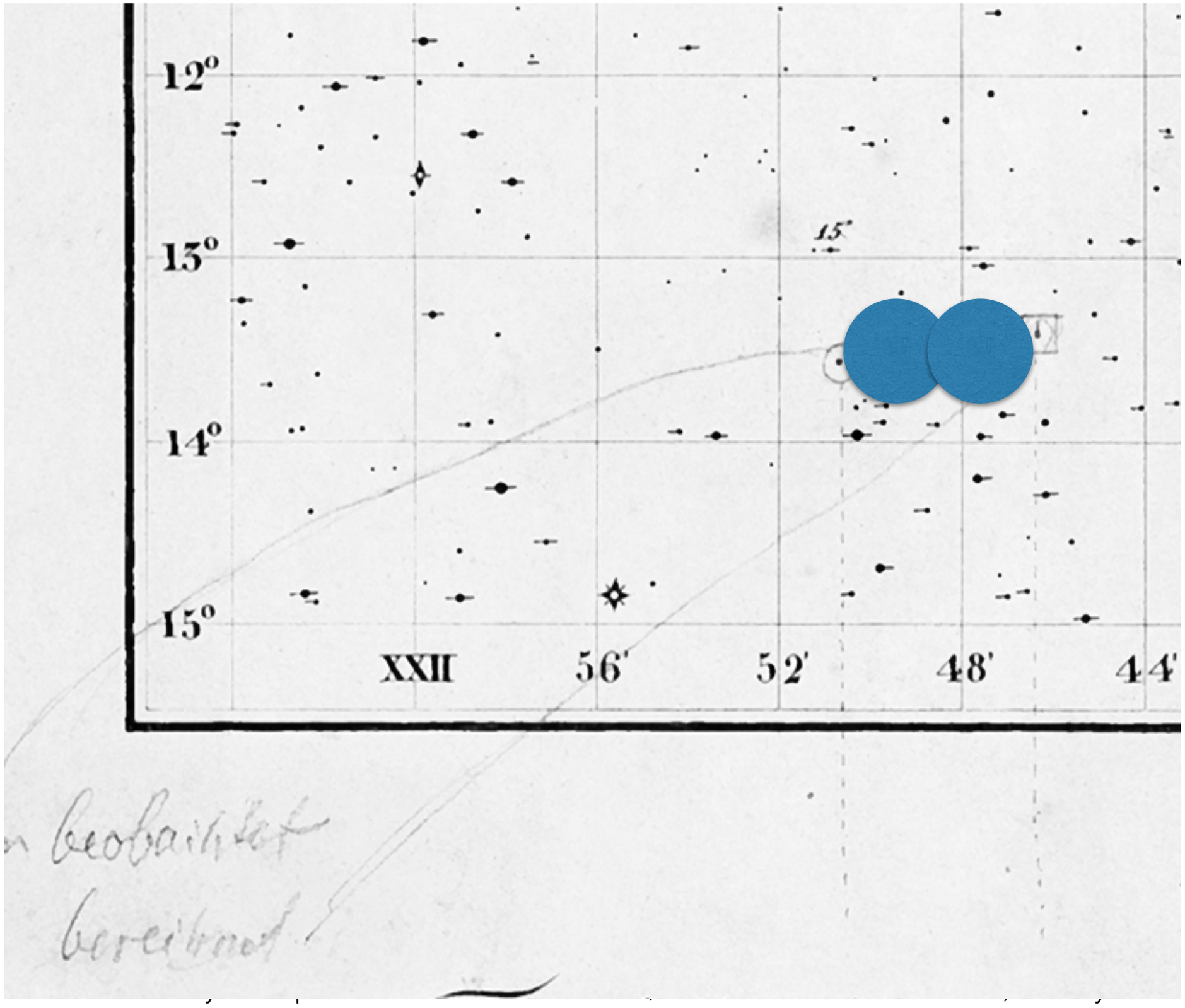


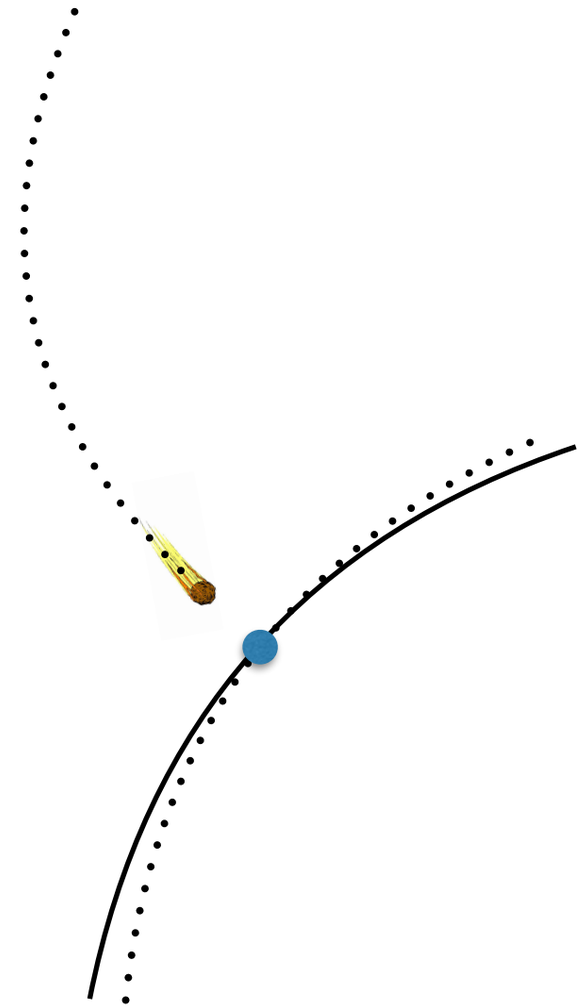
Le Verrier

- Urbain Jean Jospeh Le Verrier (11.03.1811 - 23.09.1877)
- Saint-Lô (Normandy) - Paris (at the Observatory)
- studied at the École Polytechnique
- excelled in experimental chemistry (as a semi-protégée of Guy-Lussac)
- 1837:
  - got married to Lucille Clotilde Choquet
  - applied to a position as an assistant of Guy-Lussac, Guy-Lussac took another, but fixed a job for Le Verrier: as an assistant astronomer
- need to learn celestial mechanics
- first task: stability of the solar system (improving on Laplace and Lagrange): “Sur les variations secularise des orbites planataires", 1839
- heralded as a successor of Laplace

“ambitious and with capacity for difficult and tedious work” (Grosser)

Le Verrier

- 1840-1843 works on “the theory of Mercury
  - a stalemate: not able to work out Mercury’s ephemerides
- 1844 - work on comets (linking newly discovered comets with those seen before taking into account the perturbation of Jupiter)
- 1845 - François Arago (1786 - 1853) suggest he should work on the theory of Uranus
- 5.11.1845 - “Premier mémoire sur la théorie d’Uranus” presented to the French Academy of Sciences
  - rigours investigation of the orbit of Uranus, based on two independent methods (from Laplace and his own)
  - the motion of Uranus can not be explained in any way expect by external causes, “whose effects I will evaluate in a second memoir”
  - got him elected to the Academy of Sciences
- 01.06.1846. - “Recherches sur les mouvements d’Uranus’
  - a resisting ether? - no (proposed by Encke for a comet)
  - a massive satellite of Uranus? - no
  - a crucially timed collision with a comet - no
  - an altered law of gravitation? - no (well no proof, just belief in Newton)
  - a new planet - yes



Le Verrier

- 01 June 1846 Memoir
  - altered law of gravitation: “a last resort to which he would not turn until all other potential causes for the discrepancies had beed investigated and rejected” (Grosser)
  - it has to be an unseen planet
  - where is it:
    - showed that it has to be beyond Uranus: but where?
    - Bode’s law: 2xUranus ~ 38 AU (at 3xUranus it would have too be too big)
    - in the plane of ecliptic - an assumptions based on Jupiter, Saturn and Uranus
      - mass and position - heliocentric longitude (at a given time)
  - on 01.01.1847. the unseen planet will have heliocentric longitude of $325^{o} \pm 10^{o}$ (or less)
- 31.08.1846 - “Sur la planète qui produit les anomalies observées dans le mouvement d’Uranus. - Détermination de sa masse, de son orbite et de sas position actuelle”
  - solved 33 equations to predict the properties of the planet
  - location: 326.5^{o} (on 1.1.1847)
  - mass: ~2x Uranus mass
  - size: 3.3”
- both papers are remarkable as they are directly addressing the observational astronomers where to find the planet: “5^{o} to the East of the star δ Capricorni”
- everybody applauded but a few were interested in looking

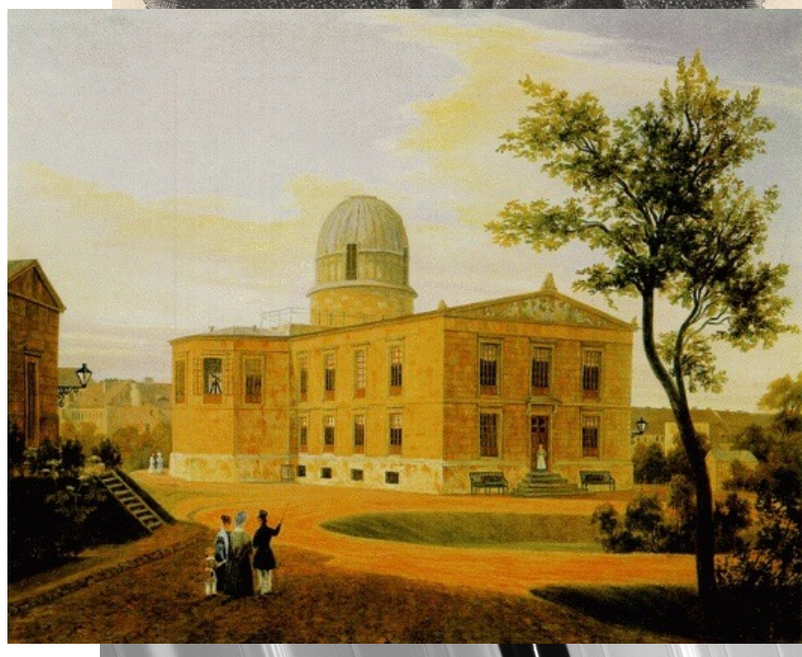
Le Verrier’s grave at Montparnasse cemetery in Paris

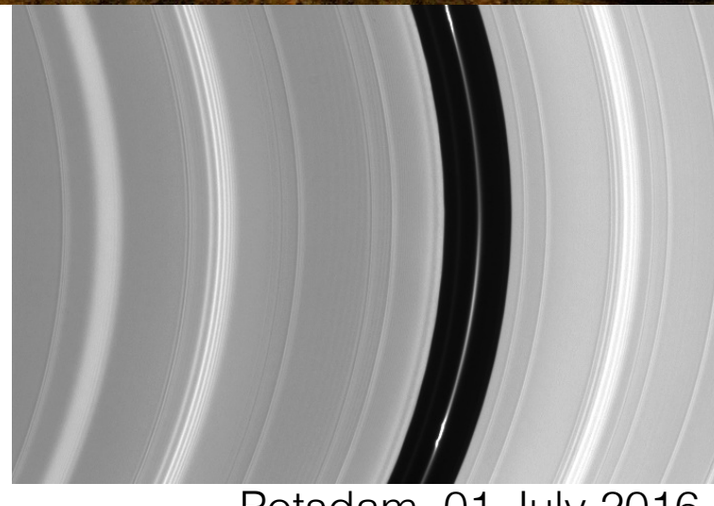
Le Verrier

- illustrious career after the discovery
- 1854 successor of Arago as the director of Paris Observatory (Monsieur Directour)
- Awards:
  - Copley Medal (Royal Society, 1846)
  - two Gold Medals of RAS (1868, 1876)
- modernised the observatory but was a kind of a tyrant: 1870 sacked, but reinstated in 1873 (with a control board)
- 1859 - showed that the precession of Mercury can not be explained by known planets
  - a possibility of a new planet: Vulcan
  - or a set of smaller bodies (a la asteroid belt)
  - Edmond Lescarbault claimed to have seen Vulcan (1859); but nothing found
  - worked on the orbit of Vulcan until the end of his life (and believed in Newtonian gravity)

Encke

- Johann Franz Encke (23.09.1791 - 26.08.1865)
- educated in Göttingen, under Gauss
- 1813-1815 solder in Hanseatic Legion to fight Napolen, reached rank of lieutenant
  - met Bernhard von Lindenau who employed him as an assistant in 1816 (Seeberg Observatory, from 1822 director)
- studied cometary orbits, got an award in 1817 (Cotta prise) - an expert on getting the orbits
- 1818 calculated an orbit of a ”new” comet that was only 3.3 years - discovery of short period comets
  - predicted its return in 1822 (seen only from southern hemisphere)
  - Encke sent the solution to Gauss, Olbers and Bessel, Gauss published it
- solar parallax (from 1761,1769 Venus transit data): “Die Entfernung der Sonne” (1822,1824)
- got the 1st (!) Gold Medal of the Royal Astronomical Society (1824)
- 1824 marries Amalie Becker (3 sons and 2 daughters)
- 1825 director of old Berlin Observatory (Bessel’s recommendation)
- 1835 director of the new Berlin Observatory
- 1837 Saturn rings (Encke’s gap)



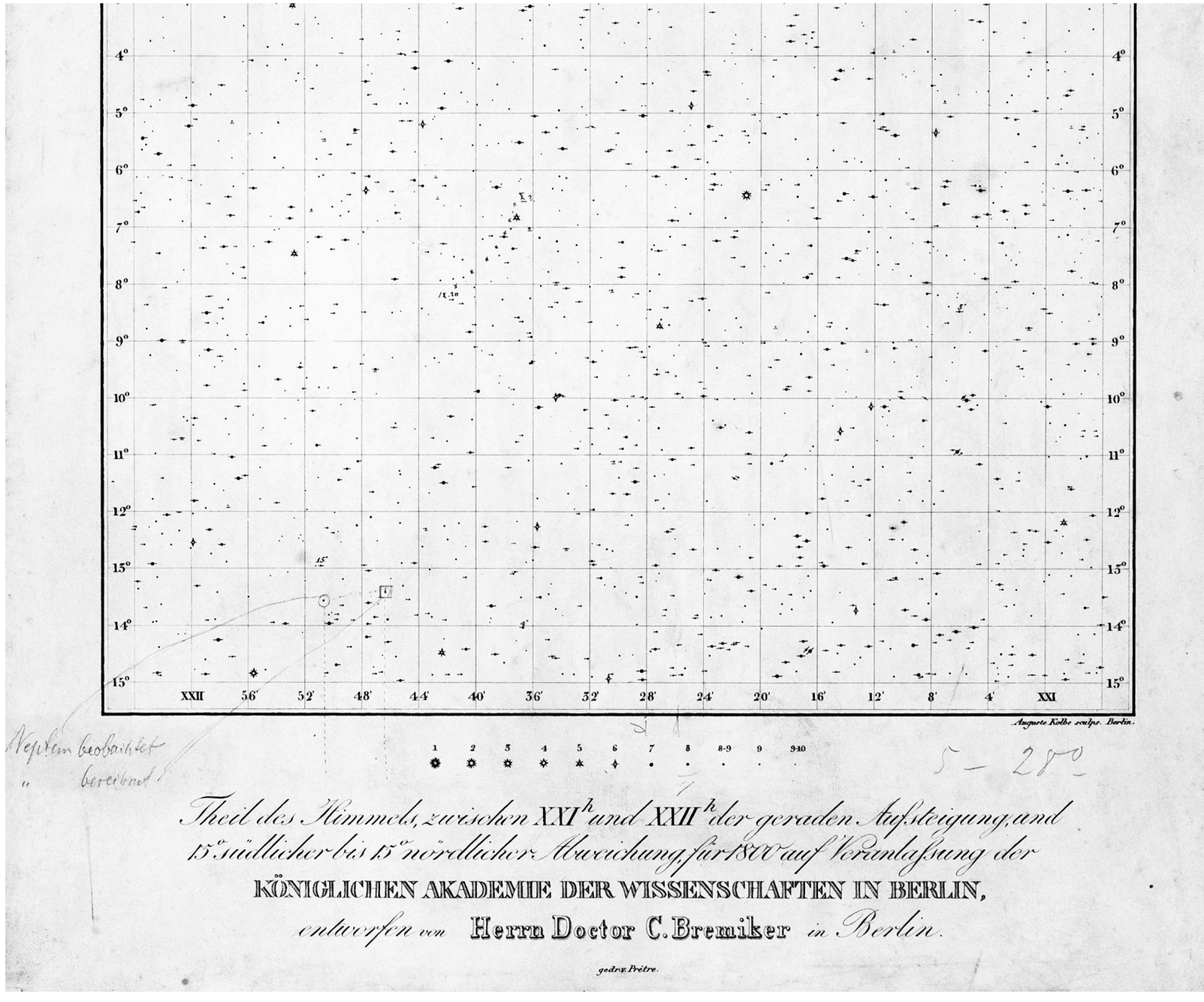


d’Arrest

- Heinrich Louise d’Arrest (13.08.1822 - 14.06.1875)
- student at Berlin, **co-discoverer of Neptune**
- 1848 - assistant at Leipzig Observatory
- professor of mathematics and astronomy
- 1851 discovered a comet
- 1857 director of the Copenhagen Observatory
- 1862 discovered an asteroid (76 Feria)
- searched for moons of Mars
- worked on stellar spectra
- 1875 received Gold Medal of Royal Astronomical Society
- married Auguste Emilie Möbius (daughter of August Ferdinand Möbius (mathematician and his boss; and a descendant of Martin Luther)

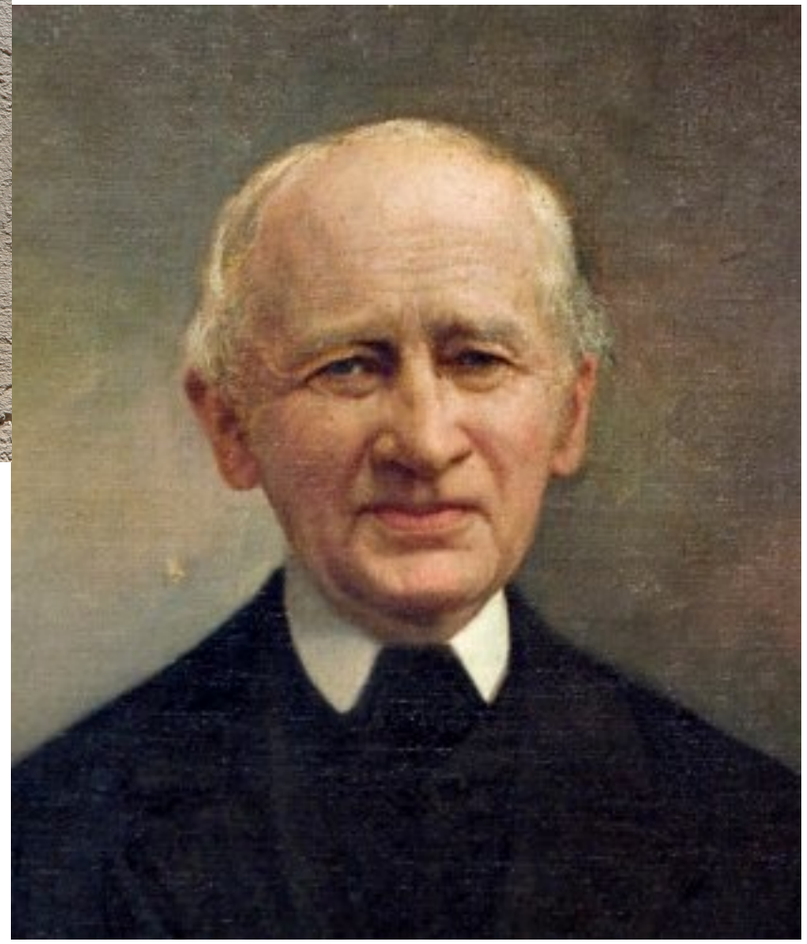
Bremiker

- Carl Bremiker (23.02.1804 - 26. 03. 1877)
- worked as on Rhenish-Westphalia geo-survey until 1835
- moved to Berlin and worked as an assistant to Encke
- 1840 discovered a comet and got a Lalande price
- 1846 - news sets of maps
- published logarithmic tables
- 1868 director if Royal Prussian Geodetical Institute

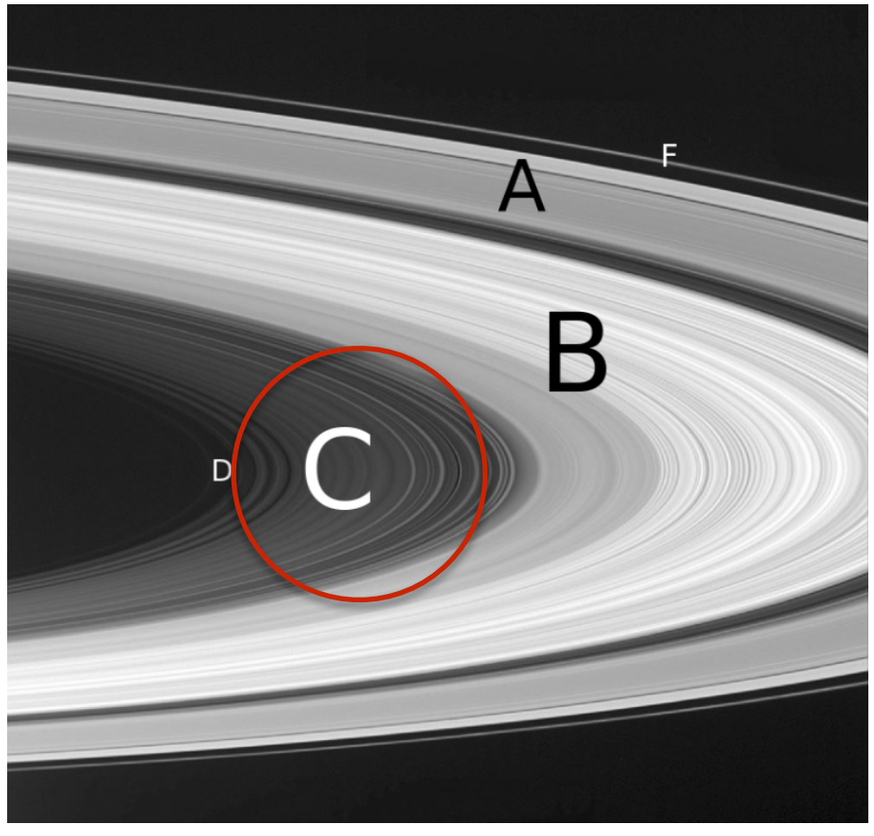


Curtesy of AIP Library

Galle



- Johann Gottfried Galle (09.06.1812 - 10.07.1910)
- Pabsthaus near Wittenberg (died in Potsdam), went to Gymnasium in Wittenberg
- studied in Berlin under Hegel, M.Ohm, Dirichlet, Encke
- works for Encke on Mercury tables
- became teacher in gymnasium in Guben, then moved to Friedrich-Werderschen Gymnasium Berlin (pay rise and closer to the action)
- 1835, new Observatory inaugurated and Galle is the 1st employee: assistant to Encke
- 1838 - discovered C ring of Saturn
  - Encke (!) didn't publish it; 1850 W. Bond and W. Dawes rediscovered it
- Dec 1839 - March 1840: discovered 3 comets - first glimpse of fame
  - Gold Medal for Art and Science from the King of Prussia
  - Lalande Prise (French Academy of Sciences) - gold medal and some cash (about a yearly salary of a gymnasium teacher)
  - 3 "Comet-medals" from King of Denmark
- 1841 J.H. Mädler tries to convicen him to move to Dorpat (Tartu) Observatory
  - Galle refuses on the grounds of distance from his family



Galle

- 1845 - PhD dissertation
  - new reduction of observations by Ole Rømer from 20-23 October 1706, 88 stars (comparison with observations of Bradley and Piazzi), the Sun, the Moon, Mercury, Venus, Mars, Jupiter and Saturn
  - sends it to Le Verrier as he knows Le Verrier is working on the orbital motion of Mercury
- Le Verrier doesn't reply until 23.09.1846 —> the rest is history
- awards:
  - Roten Adlerorden IV. Klasse (4.10.1846)
  - Légion d'honneur (9.10.1846 —11.02.1847)
  - Gold Medal from the Danish King (12.11.1847)
  - increase of salary (by about 1/3)
  - Roten Adlerorden III. Klasse (31.07.1847)
- briefly considered for a directorship of Königsberg Observatory (replacement for Bessel)
  - recommended by Encke for the job
  - opposed by Carl Gustav Jakob Jacobi
  - job went to August Ludwig Busch (Bessels' assistant)
- until 1851: helps Humboldt in calculations for his book "Kosmos"
- observes total solar eclipse (1851) in Frombork (town of Copernicus)

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

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RITE CAPESSENDIS

DIE I. M. MARTII A. MDCCCXXXXV.

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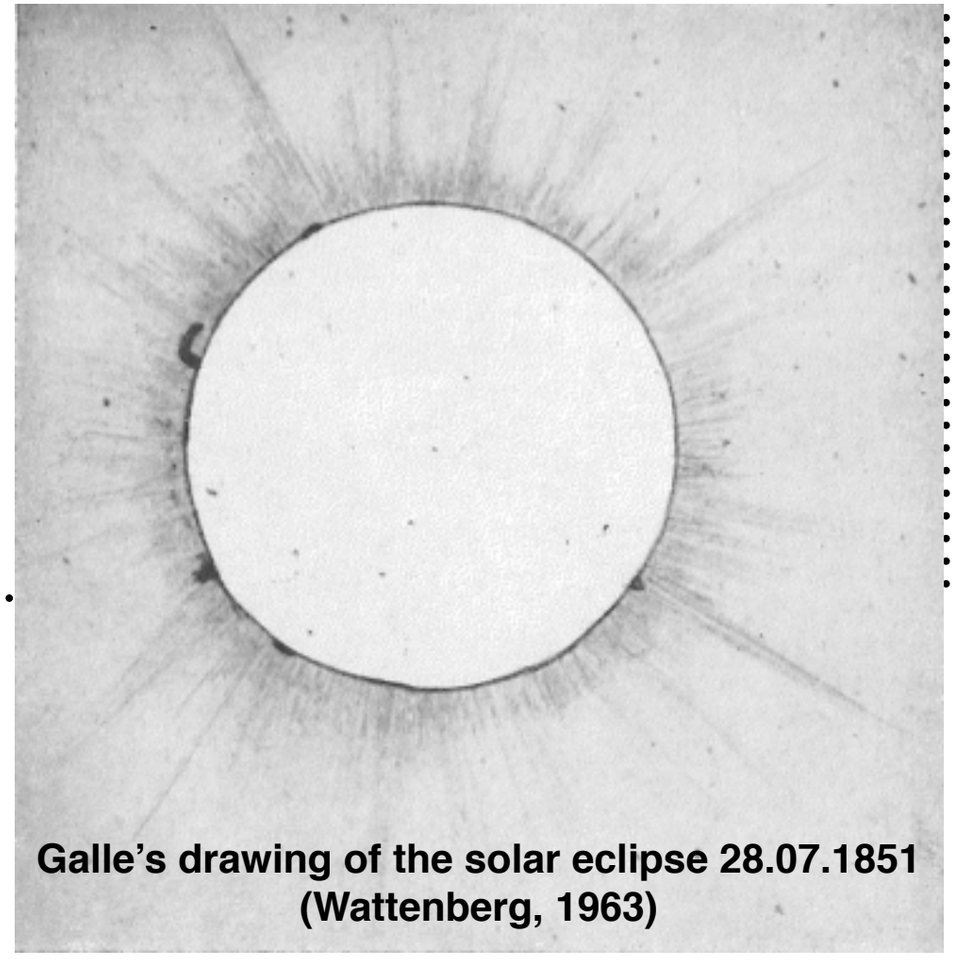
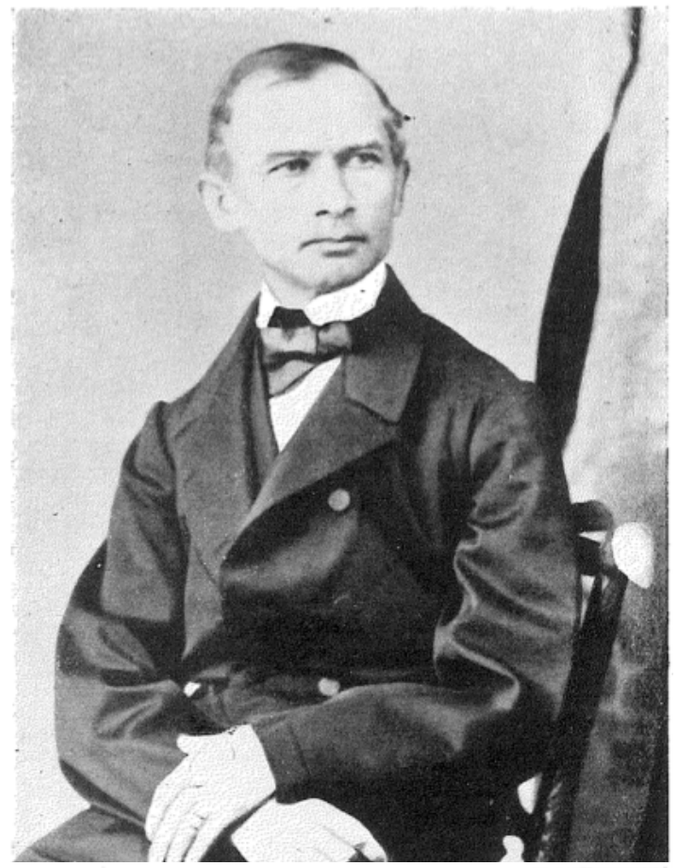


Galle's drawing of the solar eclipse 28.07.1851 (Wattenberg, 1963)

Galle



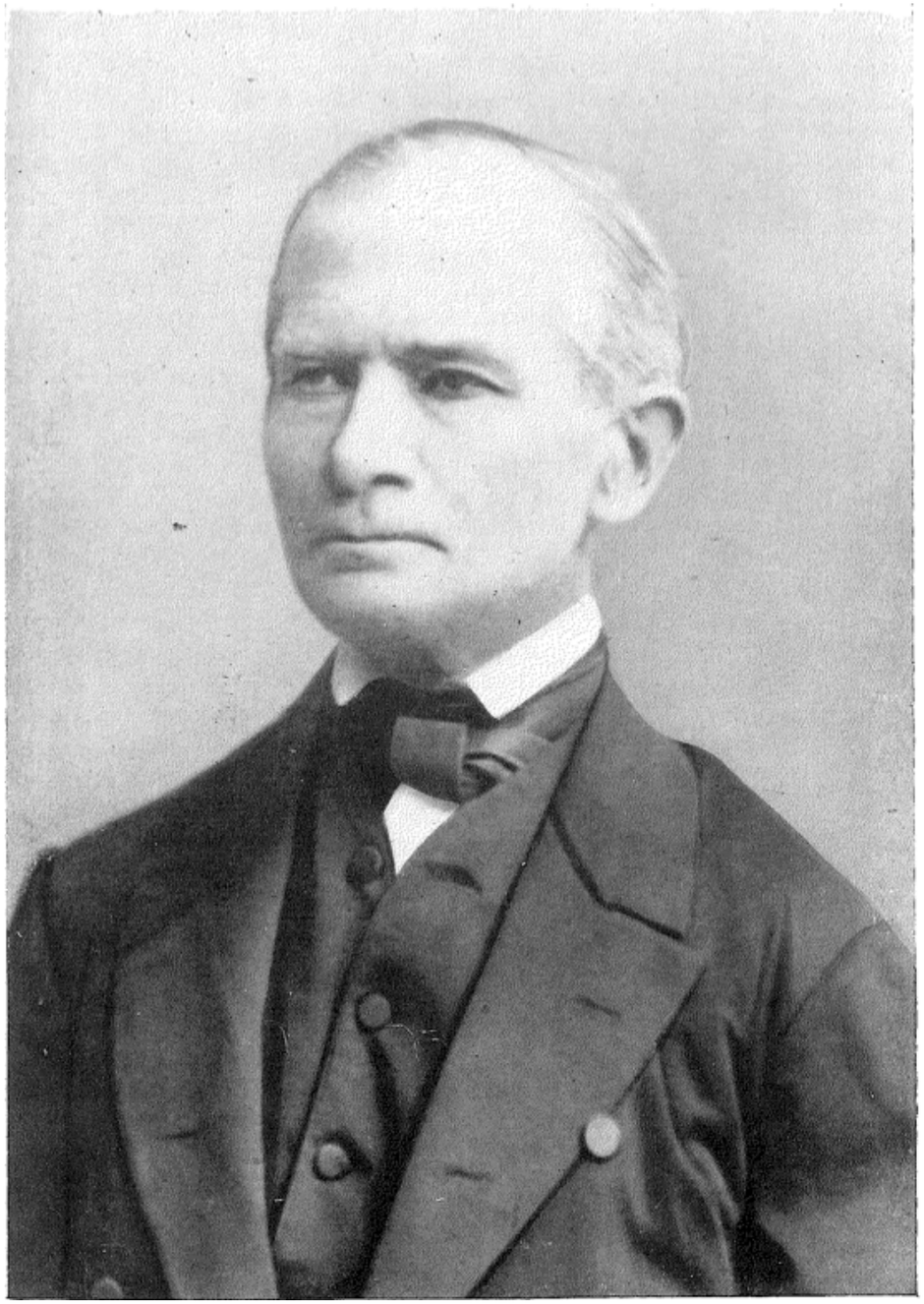
- 1851 director of Wroclaw (Breslau) observatory
- 1856 married Cäcilie Eugenie Marie Regenbrecht, daughter of a law professor in Breslau (she died 1886)
- 1872 - proposes to use minor solar systems bodies to determine the solar parallax (better than Venus as some asteroids are closer to Earth)
  - organised around the world observations (Edward James Stone (Cape Good Hope); B.A.Gould (Cordoba, Argentina), Robert L.J. Ellery (Melbourne)
  - publishes results (1875)
- lots of work on comets (old and new)

	Venus 1761-1769	Venus 1761 - 1769 (Encke)	Venus 1874 -1882	Venus 18 & 19ct (Newcomb)	Flora (Galle)	Modern
parallax [arcsec]	8.43 - 8.80	8.57	8.79-8.88	8.79±0.02	8.82±0.06	8.794143

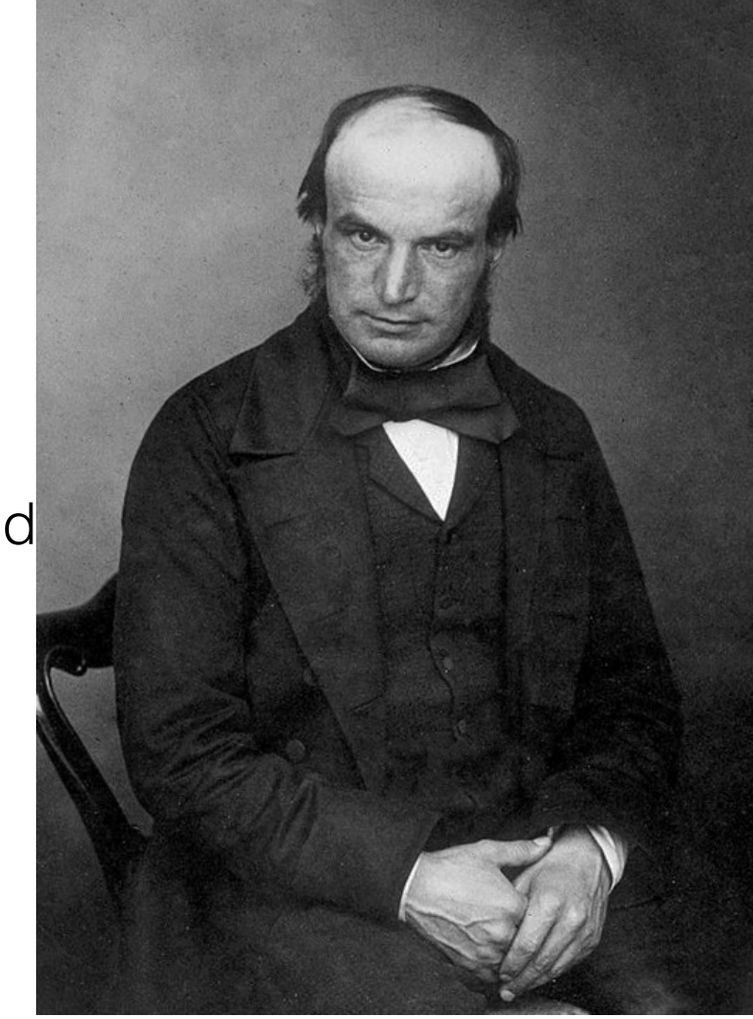
"Königsberg wäre mir für Sie lieber gewesen, aber Breslau ist dem wissenschaftlichen Verkehr näher."
Humboldt

Galle

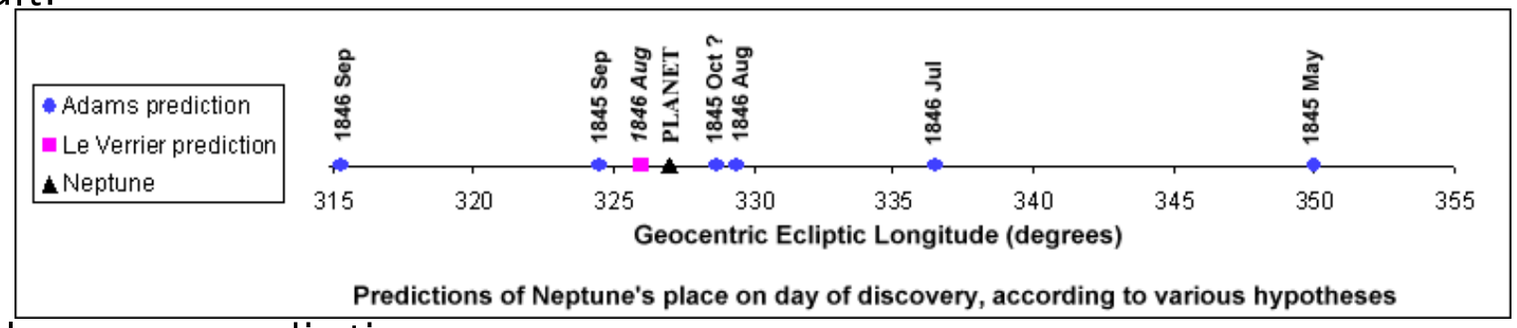
- 98 years
- born when Herschel and Lalande were still observing, died when Hubble finished his Bachelor degree
- research changed from positional astronomy and celestial mechanics to astrophysics of stars (and extra-galactic objects)
- took a ride on the first steam boat on Rhine and first train from Berlin to Potsdam
- born at the end of Napoleonic wars, lived through 1848 revolution, 1871 unification and died at the onset of arms race among European states
- is it possible there is only one biography of him? (by Diedrich Wattenberg, 1963, Leipzig)



Adams



- John Coach Adams (5.6.1819 - 21. 01.1892)
- poor family from Cornwall, but inherited some money that was used to put him to Cambridge as he showed remarkable skills in math
- 1843 graduated as the best math student (Senior Wrangler)
- tutor at St. John's college
- in free time works on the orbit of Uranus since 1843
- September -October 1845 - first result:
  - distance - Bode's law
  - longitude (1.10.1845) 323 34
  - mass: 0.0001656



Predictions of Neptune's place on day of discovery, according to various hypotheses

- After Le Verrier June memoir: several more predictions
  - more on controversy in September
- later life:
  - lunar theory
  - president of the Royal Astronomical Society (Gold Medal 1866)
  - died a rich man (equivalent of 2.6 million GBP in 2003)

Walker

- Sears Cook Walker (28.03.1805 - 30.01.1853)
- worked at US Naval Observatory
- wanted to look for Neptune (after Le Verrier results) but not allowed - observatory is busy
- are there any “pre-discovery” observations of Neptune?
- Walker searched observations of Lalande near where Neptune would have been:
  - found a star that did not appear in other catalogs (e.g. Bessel’s)
  - observed the region and did not found “the star”
  - discovered that Lalande observed Neptune on 8 and 10.05.1795 (also shown by Adolf Cornelius Petersen and published in Astr.Nach)
- Felix Mauvis showed that Lalande was aware that the location of “the star” on 8th and 10th were different, but didn’t trust them, removed one and “doubted” the other
- calculated new orbit using the observed positions and the Lalande data
- Walker new orbit was a sensation: it was completely different from Le Verrier’s and Adams’!

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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	326	328	

Orbit comparisons

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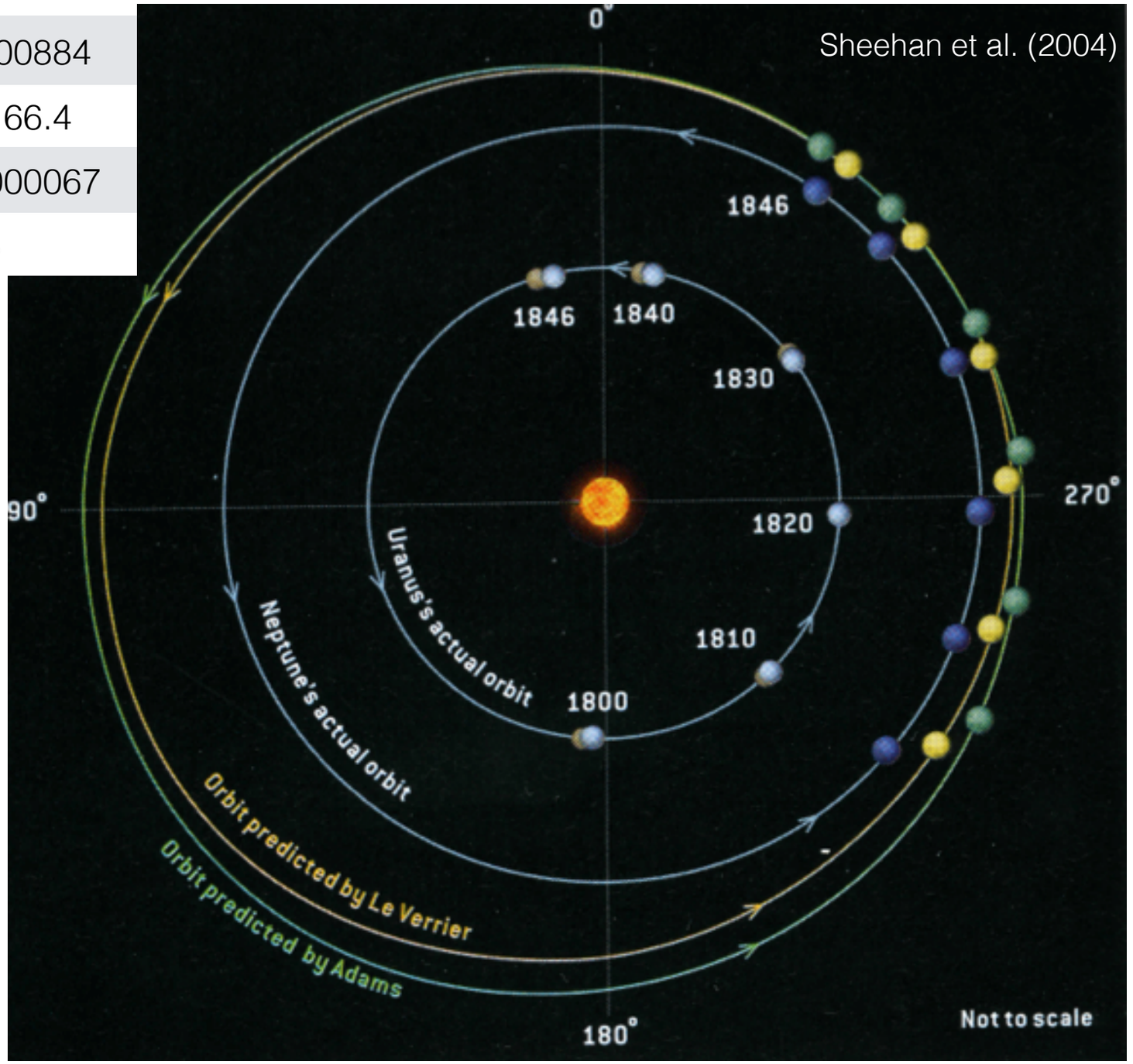
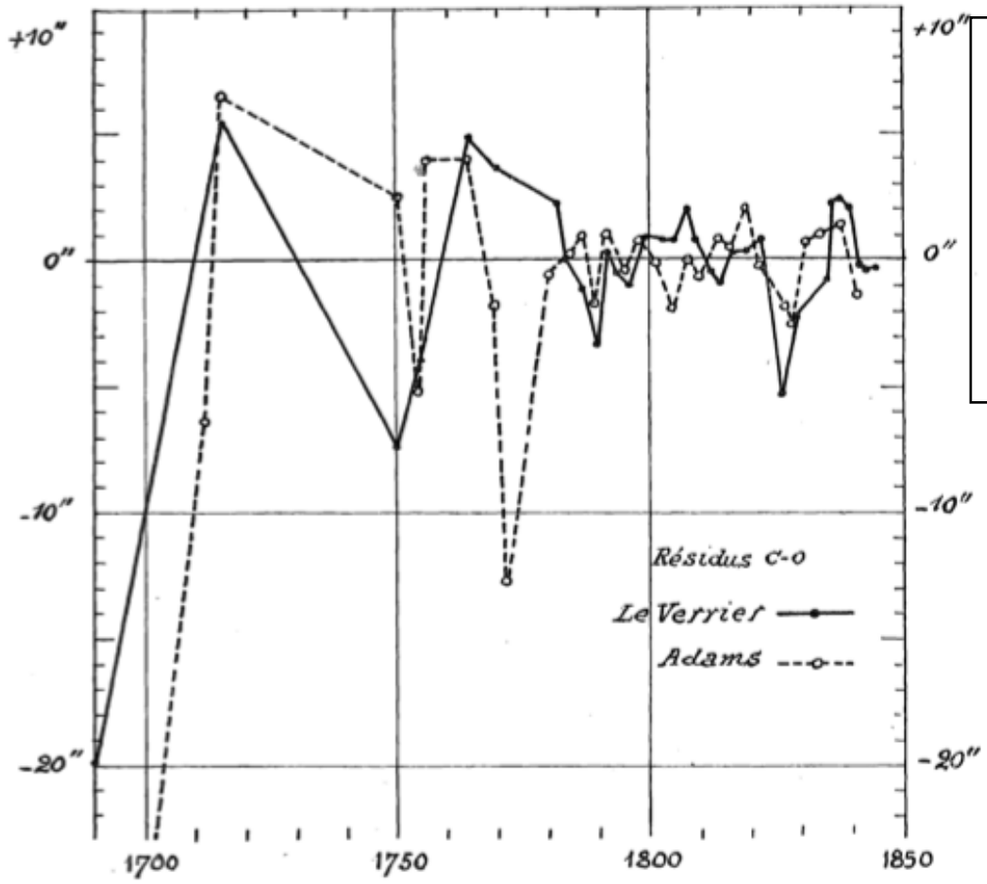
Longitude, 01.01.1847	329	326	328

1. Titius - Bode law is broken
2. almost all elements of the orbits were wrongly estimated
3. how did they find the planet?
4. fluke of orbital timing?
5. Did they actually found the planet they were looking for? (as US astronomers asked)



A lucky shot?

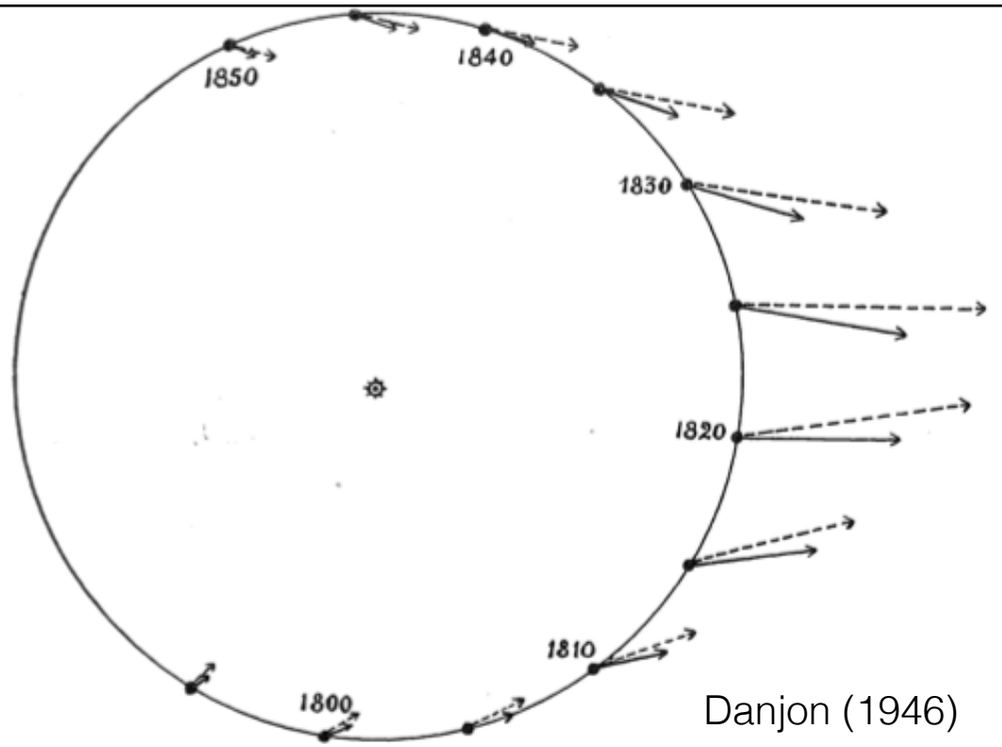
- Le Verrier's and Adams' orbit are quite similar and essentially identical around 1846
- Neptune's orbit is the most similar to predicted orbits between 1830-1850s
- most of the data came from the period after discovery of Uranus (1781)
- only half of the orbit of Uranus and a quarter of the orbit of Neptune!
- no surprise that that part of orbit was best described by both + they heavily relied to Titius-Bode law



errors in the mean longitude assuming an external planet

Danjon (1946)

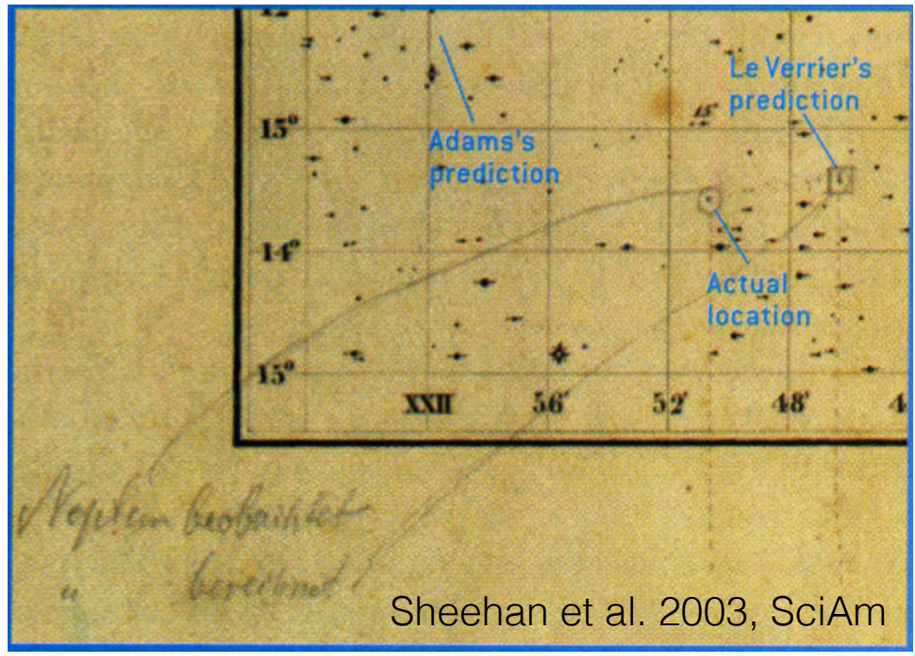
comparison of the perturbing force on Uranus by Neptune (full) and Le Verrier prediction (dashed)



Danjon (1946)

Who had a better prediction?

- Le Verrier; but both are dramatically wrong
- both use the same novel method of perturbation theory (developed by Laplace and Pontecoulant)
- both choose Bode's law - wrong
- both ignored or tried to avoid the resonances: "Laplacian librations" (Price 1847; Hubbel & Smith1992)
  - when orbital periods are integer fractions
  - for D=35.3 AU —> 2:5 resonance
  - Le Verrier and Adams could not decrease their orbit to less than that
  - but they could make it elliptical so that at the "modern" observations orbits are as close as possible
  - Uranus:Neptune are actually close to 1:2 resonance and this is what makes the perturbations so strong (Jupiter:Saturn = 2:5)



Sheehan et al. 2003, SciAm

True heliocentric longitude of Neptune on 23.09.1846: **326º 57'**

	Adams I	Adams II	Le Verrier	Le Verrier
prediction	328	329	324	325
error	1	2	-2	-0

Distances

	Mean distance	Perihelion distance	distance at discovery	eccentricity
LeVerrier August 31	36.2	32.3	33	0.11
Adams I	38	31.9	32	0.16
Adams I	36.9	32.5	32.9	0.12
Neptune	30.33	29.81		0.0094

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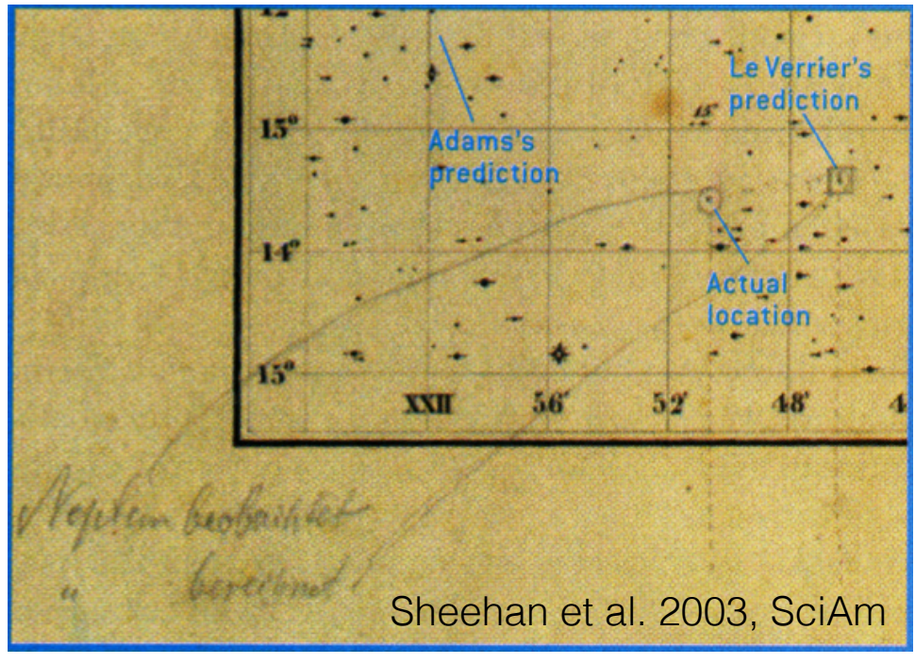
- masses were off by a factor of 2
  - Triton - Willaim Lassel (10.10.1846)



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D			-2	-0

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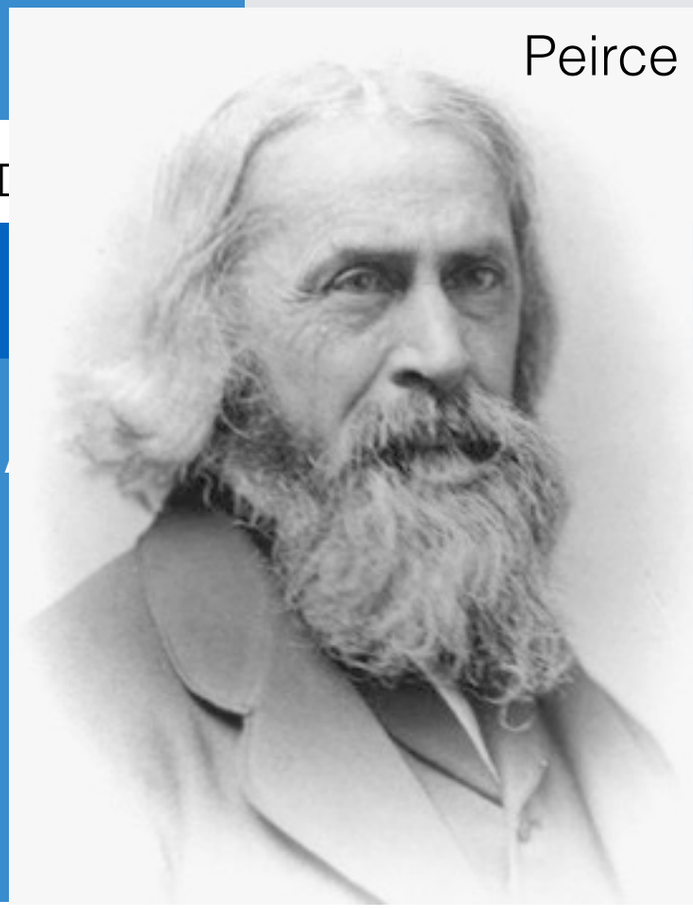
	33	0.11
	32	0.16
	32.9	0.12
		0.0094


Peirce

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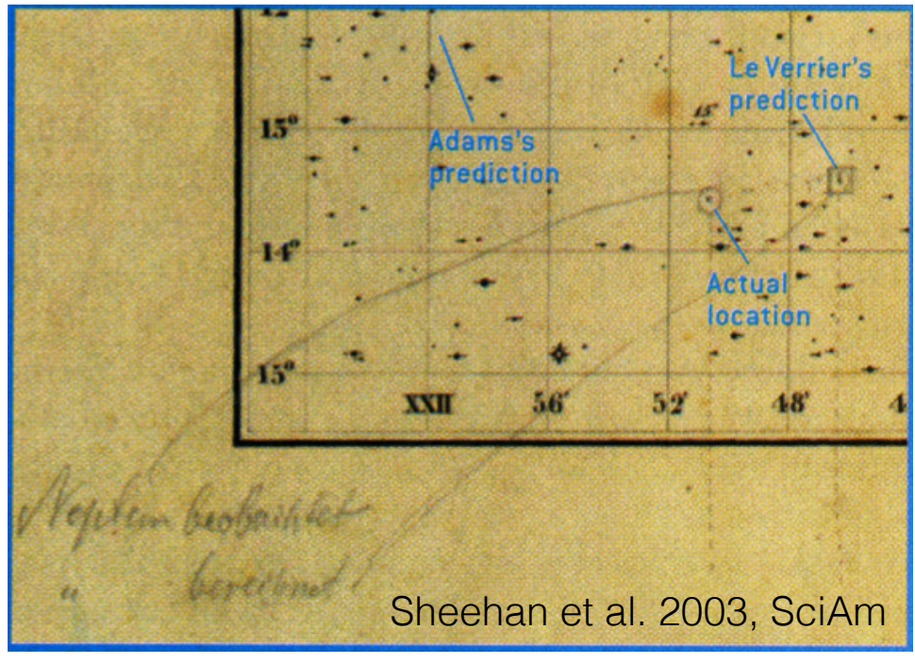
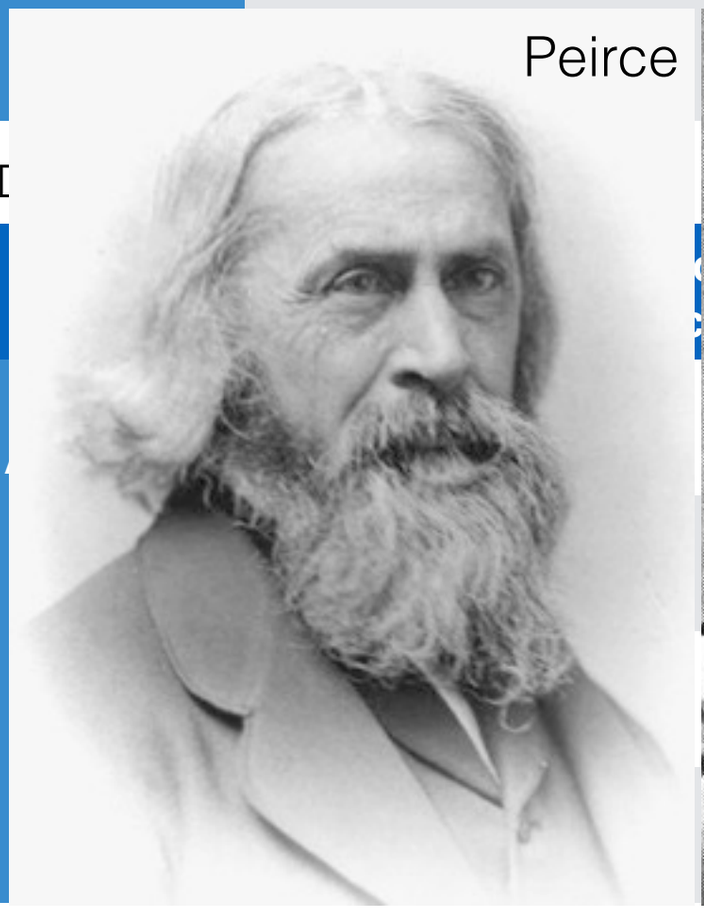
- both use the same novel method of perturbation theory (developed by Laplace and Pontecoulant)
- both choose Bode's law - wrong
- both ignored or tried to avoid the resonances: "Laplacian librations" (Price 1847; Hubbel & Smith1992)
  - when orbital periods are integer fractions
  - for D=35.3 AU —> 2:5 resonance
  - Le Verrier and Adams could not decrease their orbit to less than that
  - but they could make it elliptical so that at the "modern" observations orbits are as close as possible
  - Uranus:Neptune are actually close to 1:2 resonance and this is what makes the perturbations so strong (Jupiter:Saturn = 2:5)
- masses were off by a factor of 2
  - Triton - Willaim Lassel (10.10.1846)
- 4.4.1848 Benjamin Peirce announced that the Neptune (true mass and orbit) is the perfect explanation for the motion of Uranus (including 1690)



Sheehan et al. 2003, SciAm

True heliocentric longitude of Neptune on 23.09.1846: **326º 57'**

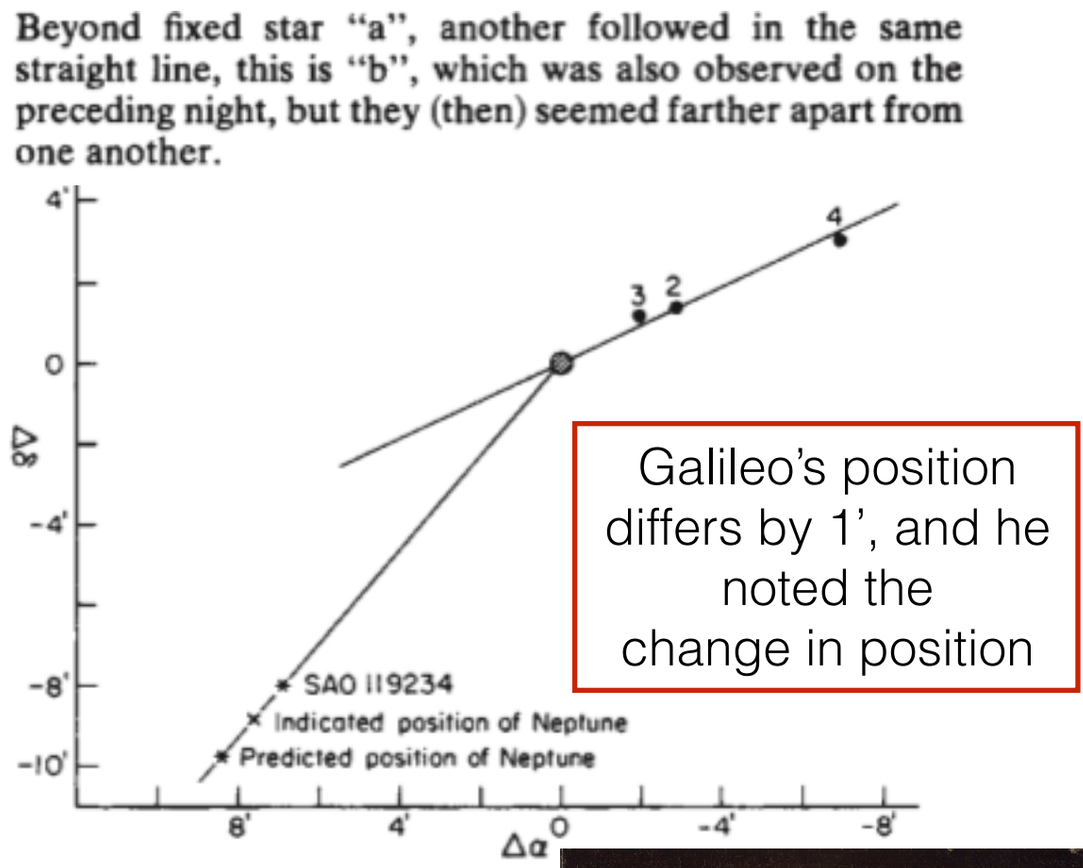
	Adams I	Adams II	Le Verrier	Le Verrier
prediction	328	329	324	325


Peirce


Lassel

Was Neptune observed more than once?

- visible through telescope only
- look for historical records of telescope observations when Neptune was close to other planets (i.e. Jupiter)
- Jupiter - Neptune: January 1613, September 1702
- Kowal & Drake (1980) looked at the logbooks of Galileo



Galileo's position differs by 1', and he noted the change in position

Kowal & Drake, 1980, Nature

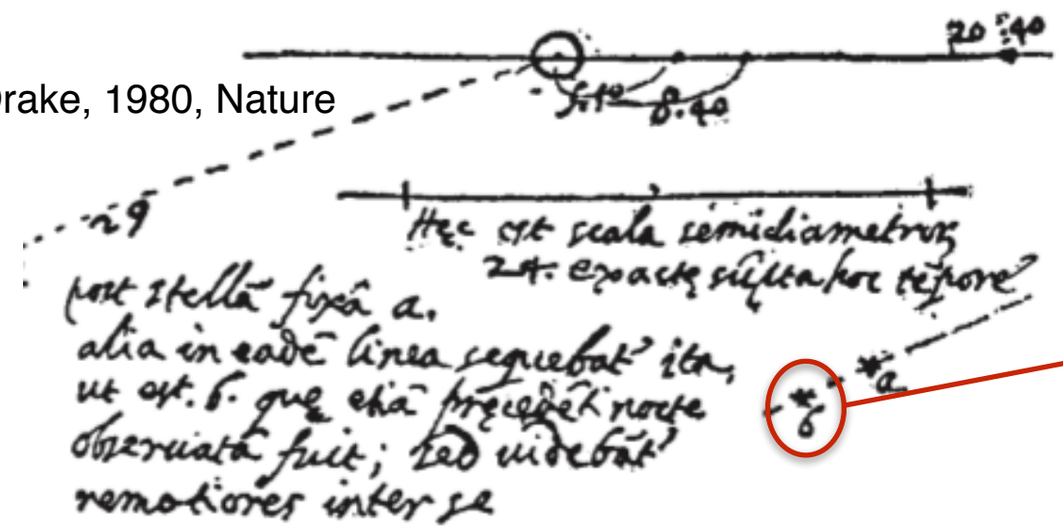
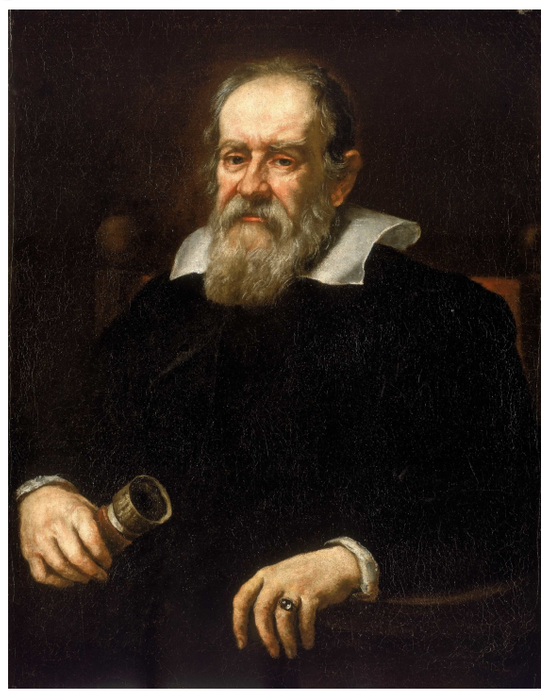


Fig. 4 Galileo's notebook for 26/27 and 27/28 January 1613.

Galileo's observations of Jupiter and Neptune



To be continued: the juicy parts

- Did anybody actually look for Neptune?
- Embarrassment of the naming
- Did the British steal Neptune?
- Press war
- Somebody did steal all the Airy's files!
- Any lessons 170 years later (just over 1 yr on Neptune!)