JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

# Discovery of the Ice Giant Systems

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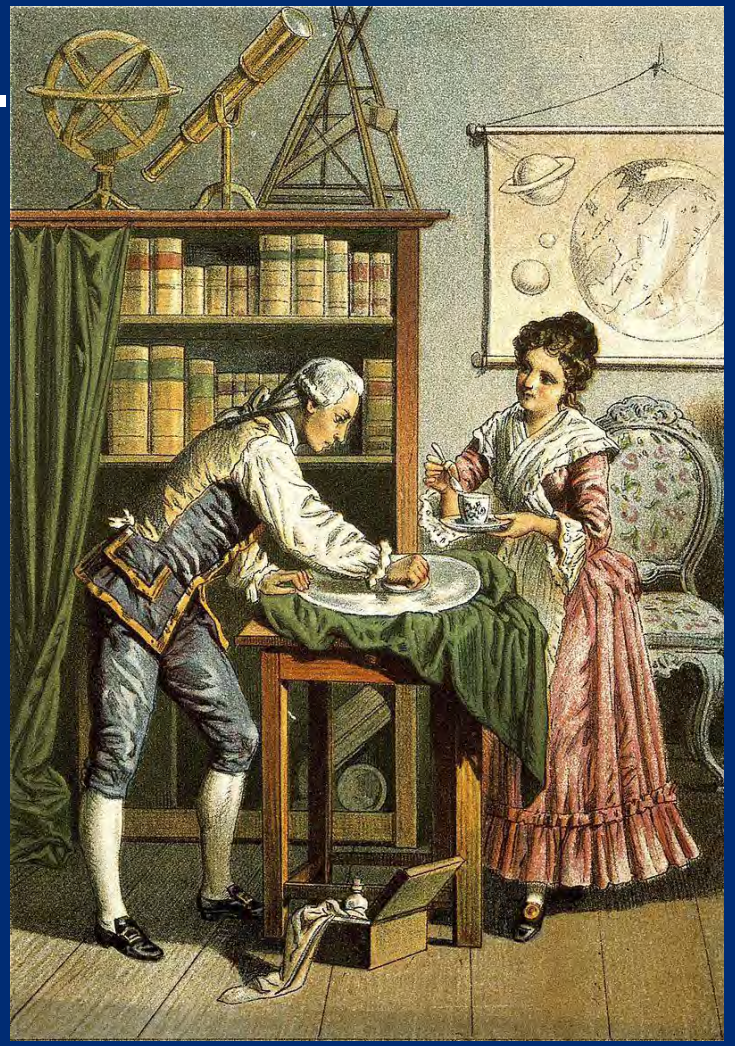
# In the beginning, there were six planets……

# And so it remained until March 13, 1781.

- William Herschel,refugee musician and astronomer discovered object in search for double stars using 6.2in telescope
- Initially thought to be a comet. Near-circularity of orbit slowly emerged



# ( Interlude)

- Titius in 1766 had noted progression of orbital distances (plagiarized in 1772 by Bode).
- Orbital radius (10ths of AU) = 4 (M), 7 (V), 10 (E), 16 (M), 28 (?), 52 (J), 100 (S), 196..
- Uranus just happened to ~fit (192) !
- Then in 1801 Piazzi discovers Ceres (27.7) !
- Picture gets rapidly confused – Olbers discovers Pallas in 1802; Herschel(s) measure them to be small, suggests ‘asteroids’. Juno 1804, Vesta 1807……

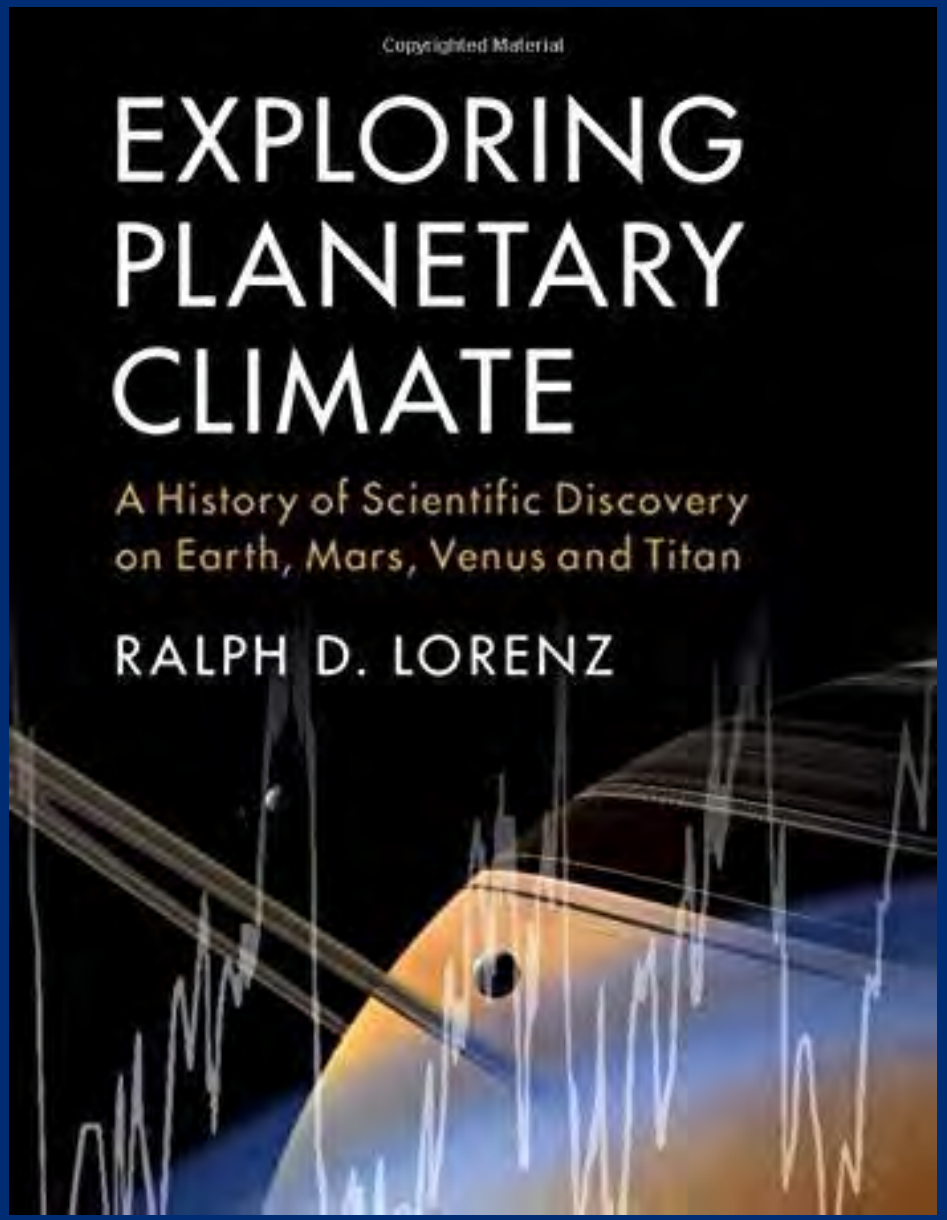
# The Discovery of Neptune

**A tale of ego, telescopes and mathematical tables**

M. Grosser, The Discovery of Neptune, Harvard 1962

T. Standage, The Neptune Files, Penguin 2001

**For other fun stories, see**

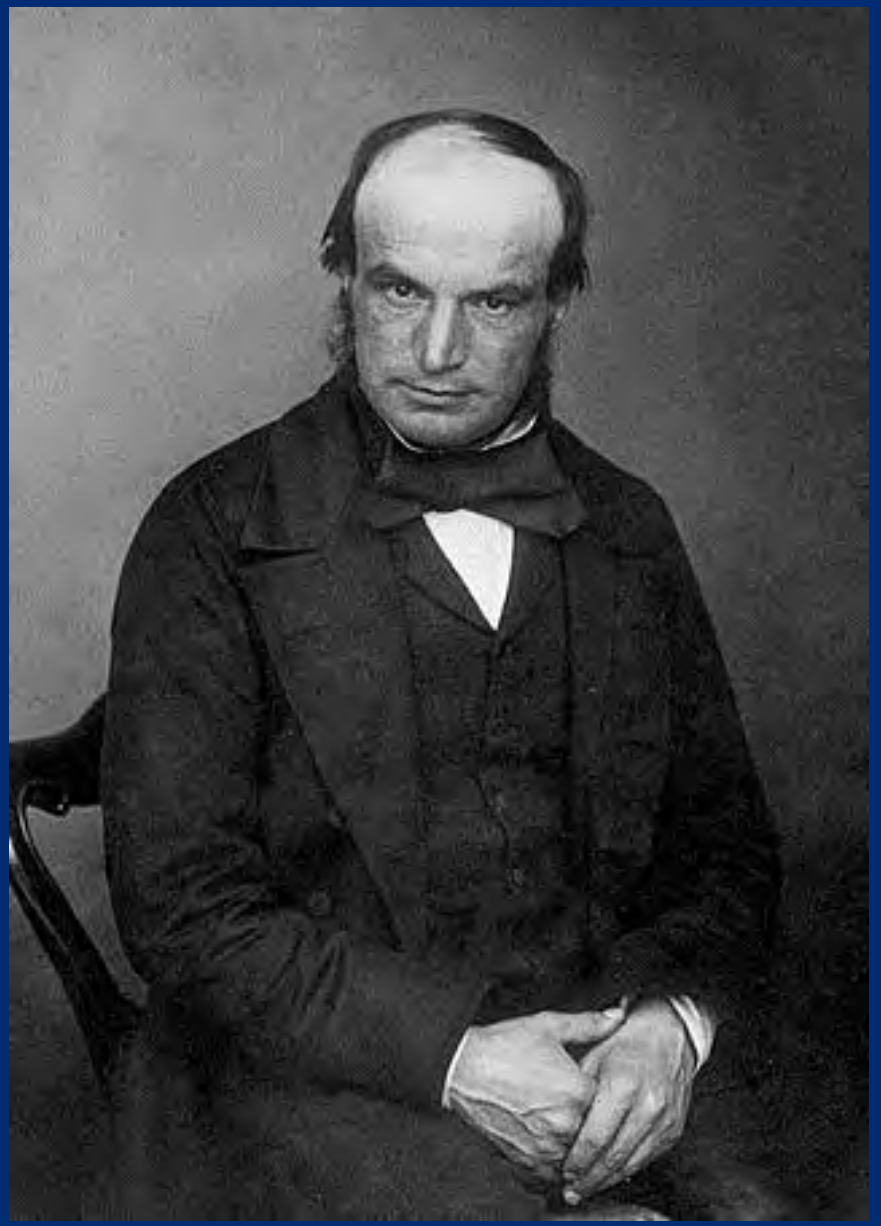


# Discovery of Neptune : Dramatis Personae

- Hero : John Couch Adams
- Antihero : Urbain Jean Jacques Le Verrier
- Villain : George Biddel Airy
- Hapless Victim : James Challis
- Supporting Roles :
  - Francois Arago
  - Johann Galle

# John Couch Adams

- Brilliant, if slightly disorganized, modest and unconfident
- Decides (1841) at age 22 to investigate ‘as soon as possible after taking my degree, the irregularities in the motion of Uranus..in order to find whether they may be attributed to the action of an undiscovered planet beyond..’



# George Biddell Airy

- Astronomer-Royal at Greenwich
- Cambridge Graduate
- Fastidious – ‘never threw away a piece of paper in his life’. Fond of double-entry book-keeping.
- Methodical – ‘safe pair of hands’, called upon by government to advise on railways, weights & measures, Babbage’s engine, etc.
- Somewhat skeptical of theoreticians

# Urbain Jean-Joseph LeVerrier

- Initially promising career as a chemist with Gay-Lussac, became astronomer by accident. Studied the stability of the solar system, then capture of comets into short orbits by Jupiter.
- Arago suggests he look into Uranus (summer 1845; Leverrier is 34)
- Confident and ambitious. “I do not know whether M. LeVerrier is actually the most detestable man in France, but I am quite certain he is the most detested”

# James Challis

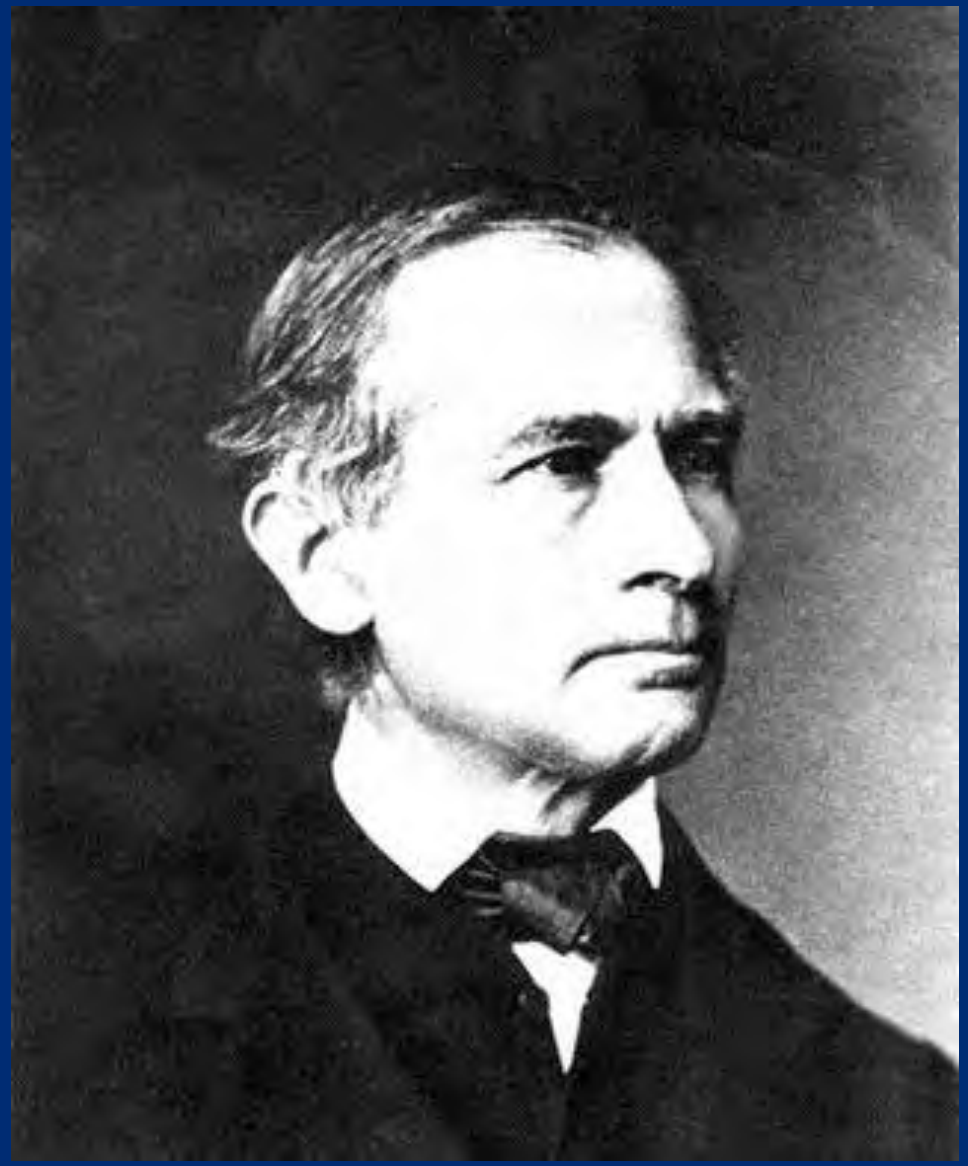
Director of the Cambridge Observatory, equipped with 11-inch (larger than Greenwich telescopes)

Initial interlocutor between Adams and Airy

Began sweep in July 1846

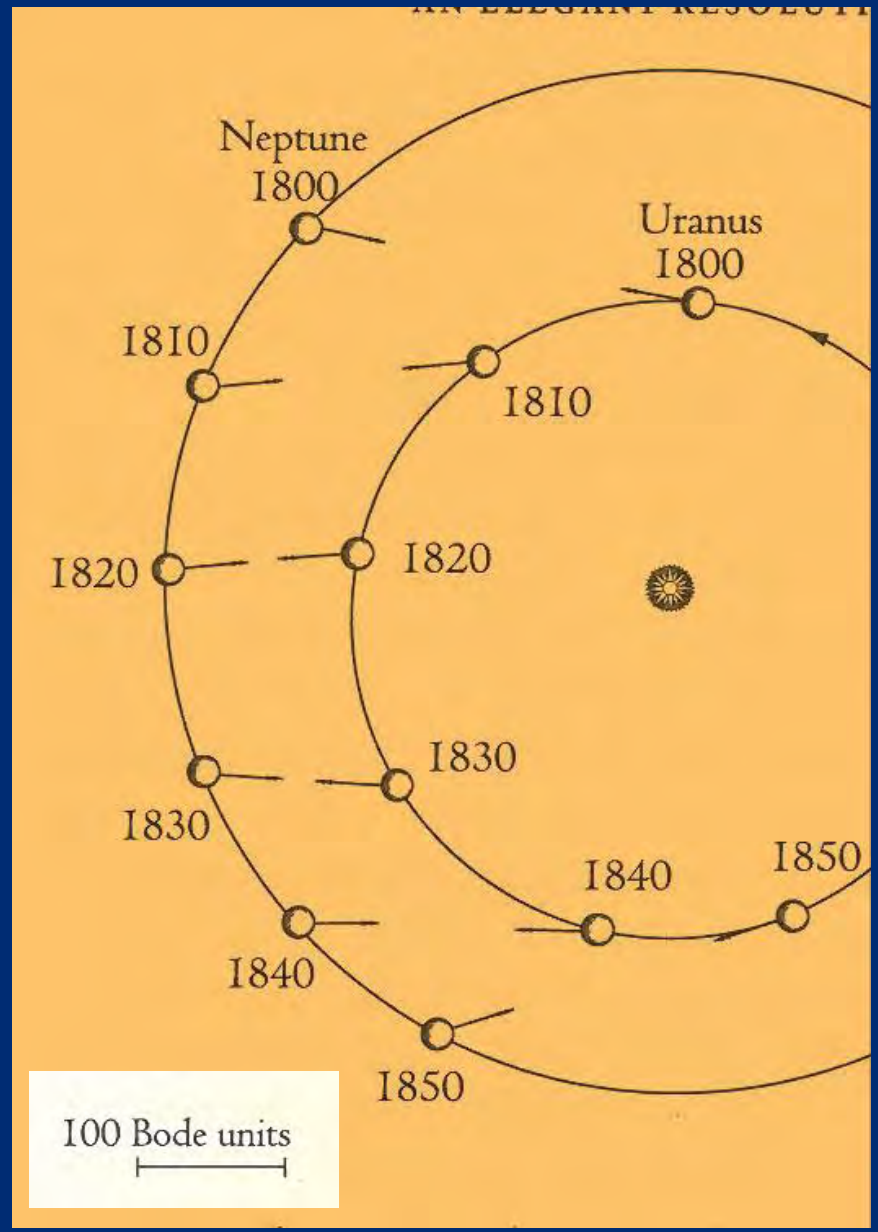
# Johann Gottfried Galle

- Assistant Astronomer at Berlin Observatory. First saw Neptune and knew what it was



# Prelude : The Problem

- Observations of Uranus' position diverge from predicted orbit
- Impossible to fit old observations (1800-1830) and new ones : temptation to dismiss older ones as inaccurate (not helped by some typos in publication)
- But divergence gets worse and worse
- Alternate explanations offered : inverse square law not quite right (qv 'Pioneer Effect'), some substance in space causing 'drag', or a perturbing body



# The Problem

- Many unknown terms
- Need to invoke priors to reduce solution space. Why not use Bode's Law? 38.4 AU…
- Solution developed by Adams in September 1845, discussed with Challis
- Challis urges communication to Airy. Mischance prevents meeting.

$$
\begin{aligned}
c'' = {} & \partial e + \partial x_1 \cos\{13°0.5'\}t + \partial x_2 \cos\{26°1.0'\}t \\
& t\partial n + \partial y_1 \sin\{13°0.5'\}t + \partial y_2 \sin\{26°1.0'\}t \\
& + h_1 \cos\{8°24.6'\}t + h_2 \cos\{16°49.2'\}t + h_3 \cos\{25°13.8'\}t \\
& + k_1 \sin\{8°24.6'\}t + k_2 \sin\{16°49.2'\}t + k_3 \sin\{25°13.8'\}t \\
& + p_1 \cos\{4°36.0'\}t + p_2 \cos\{3°48.6'\}t + p_3 \cos\{12°13.2'\}t \\
& + q_1 \sin\{4°36.0'\}t + q_2 \sin\{3°48.6'\}t + q_3 \sin\{12°13.2'\}t
\end{aligned}
$$

FIGURE 14: Adams's equation. The discrepancy ($c''$) between the observed and calculated positions of Uranus is related to eighteen unknown constants ($\delta e$, $\delta x_1$, $\delta x_2$, $\delta n$, $\delta y_1$, $\delta y_2$, $h_1$, $h_2$, $h_3$, $k_1$, $k_2$, $k_3$, $p_1$, $p_2$, $p_3$, $q_1$, $q_2$, $q_3$) for twenty-one values of t, each of which corresponds to a particular year. The eighteen unknown constants are themselves combinations of the unknowns giving the corrections to the true ellipse for Uranus and the characteristics of the unseen planet.

- Meanwhile LeVerrier develops a solution and presents theory of Uranus' motion to French Academy of Sciences in November 1845

# The Non-Discovery

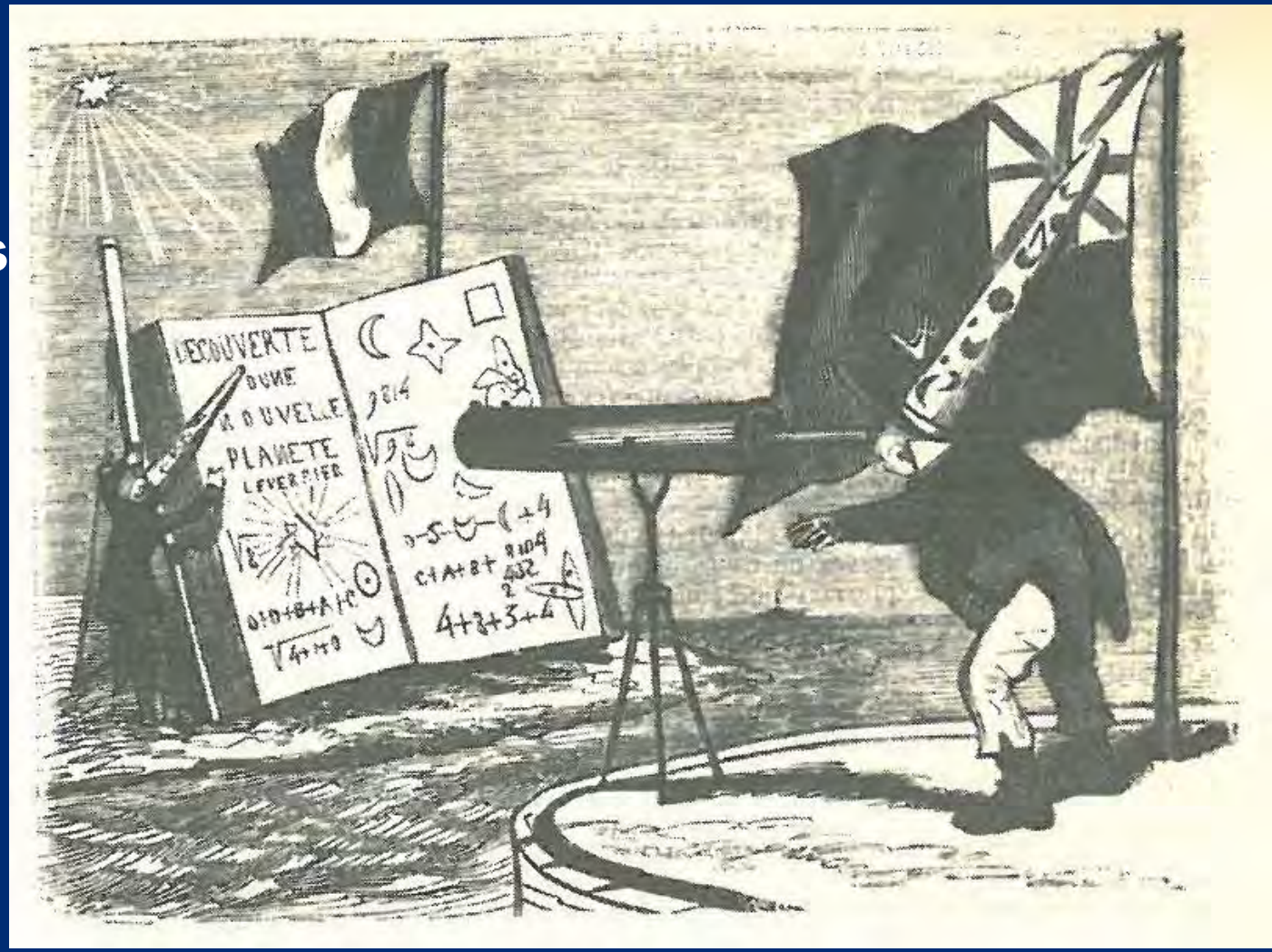
- Airy ignores Adams at first
- On hearing of LeVerrier's independent determination of a position near that of Adams  (actually, a region in mass/longitude space), in July 1946 Airy finally instigates an 'urgent' search
- Airy instructs Challis at Cambridge to sweep a target area (30 deg long by 10 deg high) three times to obtain robust detection
- Both Adams and LeVerrier are continually updating estimates of position. Despite predicting a readily-observable diameter, LeVerrier fails to persuade French observers to search.
- (retroactive analysis would show that Challis observed Neptune in August, twice, in the first 4 days of searching, but data reduction had been lagging)

# The Discovery

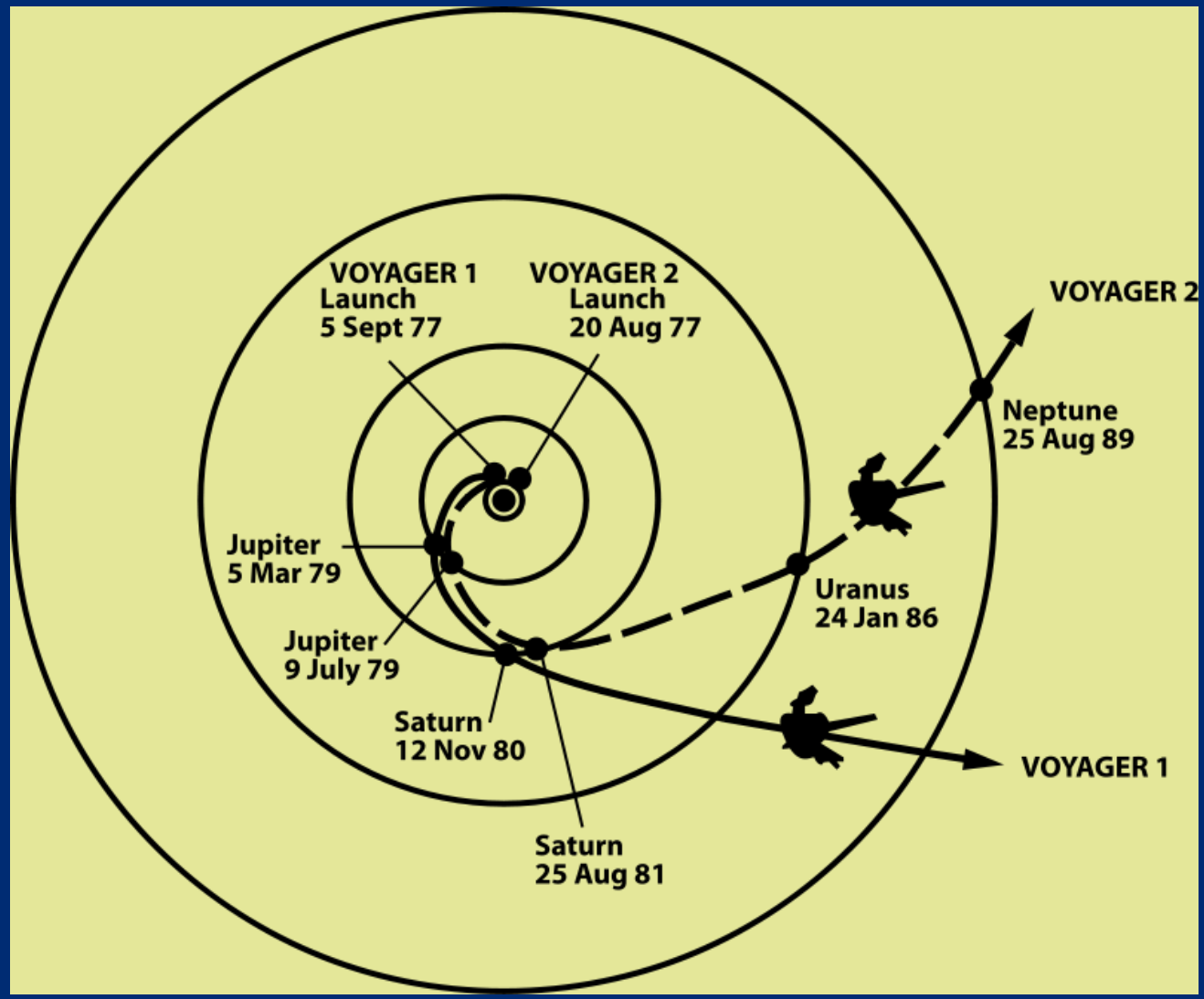
- LeVerrier gives up on France, decides to contact Johann Galle who *a year before* had sent him a copy of his thesis. Galle is an assistant astronomer (Encke is the director of the Berlin Observatory). LeVerrier sends request on 18th September 1646, reaches Galle on 23rd.
- Galle tries to obtain Encke's permission to indulge in search: Encke expresses skepticism, but relents. Galle and d'Arrest perform search at LeVerrier's predicted location
- After initial open-loop sweep was unsuccessful, they check against new (not yet distributed) Berlin Star Atlas. Discover an 8th magnitude object not in the catalog, only 1° from LeVerrier's target spot.
- Next day determine motion and measure disk to be ~3 arcsec across

# The Aftermath

- Much Anglo-French rancour
- Proposal to name planet ‘LeVerrier’ (Arago recognized this would require retroactive naming of Uranus as ‘Herschel’)
- Royal Society credit LeVerrier with discovery.
- Challis contrite. Adams contrite. Airy heavily criticised.
- Adams and LeVerrier meet. Get on famously
- LeVerrier directs, later ousted from, Paris observatory



- Grand tour of outer solar system a unique opportunity. G. Flandro (JPL), see also Minovitch.
- Voyager mission originally only for Jupiter/Saturn
- Voyager encounters with Uranus, Neptune incompatible with Titan radio occultation experiment. Successful execution allowed Voyager 2 to be directed to U & N.
- Encounters demanded much (DSN upgrade, motion compensation for long exposures, etc.)



# Uranus

- Rings discovered in stellar occultation observed from Kuiper Airborne Observatory by J. Eliot et al. in 1977

- Voyager encounter 1986 : diverse satellites, unusual magnetic field orientation

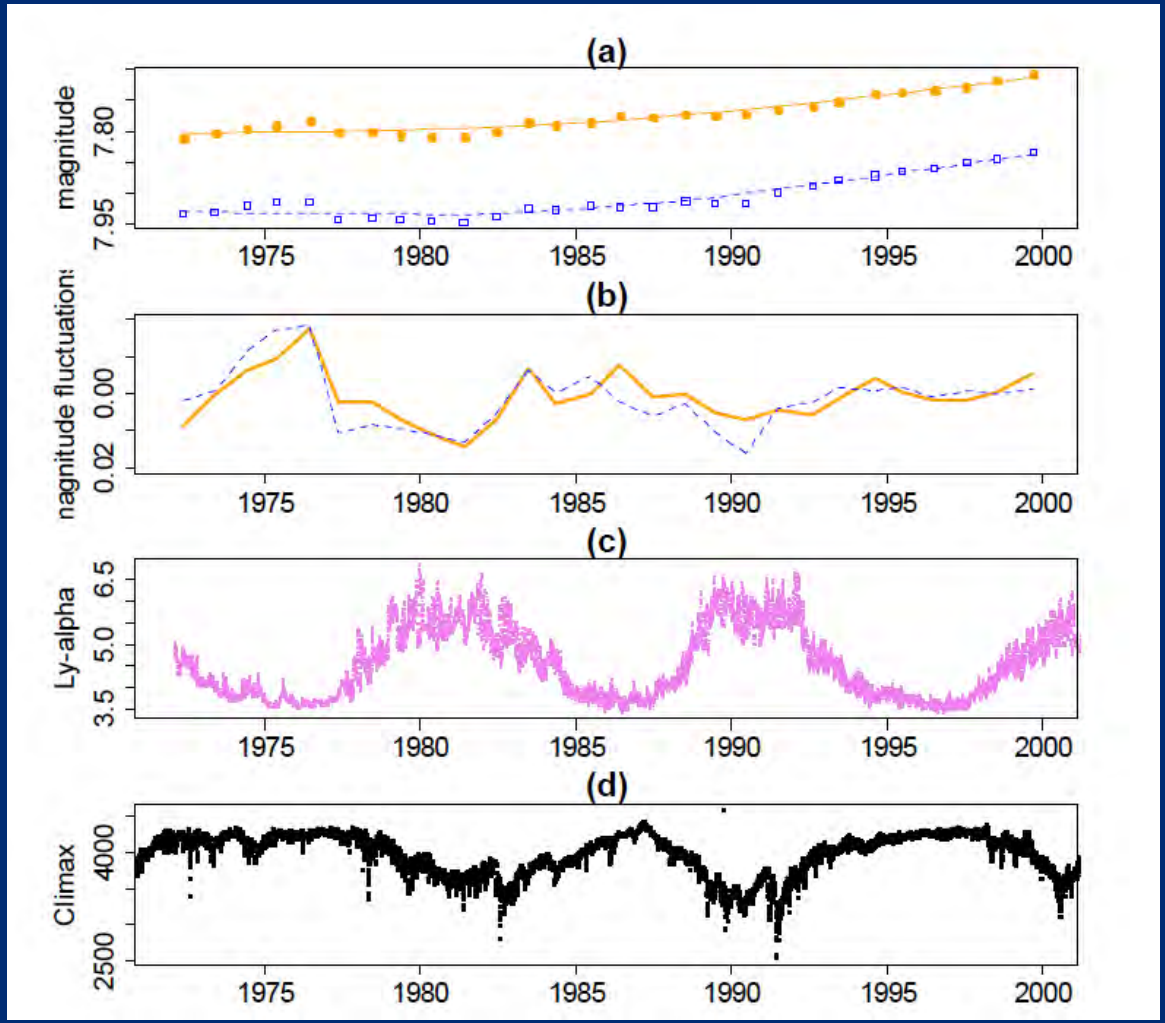
# Neptune

- Lassell quickly (1846) revealedTriton, in unusual orbit around Neptune
- Voyager encounter 1989.  Great Dark Spot.  Ring arcs.
- Stellar occultation of Triton in 1997 suggest atmospheric changes

# Does Cosmic Ray Flux influence condensation on Neptune ?

Long term monitoring of Naptune albedo shows changes unrelated to simple seasonal cycle. Could they be due to solar cycle effects directly (UV flux affecting photochemical production) or indirectly (solar wind anticorrelates with cosmic ray flux, which could influence ionization/condensation)

Aplin, K.L. and Harrison, R.G., 2016. Determining solar effects in Neptune's atmosphere. *Nature communications*, *7*, p.11976.



# Closing Thoughts

- Communication is a vital part of the scientific process !
- At the cutting edge of science, you don’t know what is right.
- Luck can play a big role
- Personalities matter !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