Title: NewtonÂ’s Methodology

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Abstract: NewtonÂ’s methodology is significantly richer than the hypothetico-deductive model. It is informed by a richer ideal of empirical success that requires not just accurate prediction but also accurate measurement of parameters by the predicted phenomena. It accepts theory mediated measurements and theoretical propositions as guides to research Kuhn has suggested that along with revolutionary changes in scientific theory come revolutionary changes in methodology. I will argue that, when Einstein found his theory could handle the Mercury perihelion problem, EinsteinÂ’s theory was doing better than NewtonÂ’s theory on NewtonÂ’s standard. The richer themes of NewtonÂ’s methodology continue to be strikingly realized in the testing frameworks for General Relativity.

Newton's Methodology

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Outline

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1. Newton's Methodology vs. Hypothetico-deductive model

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2. Newton's classic inferences from phenomena

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   a) The classic problem: Hall's Hypothesis and Brown's measurement

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    b) Einstein and General Relativity: An answer to Kuhn's challenge on criteria across revolutions

    c) The Dicke-Goldenberg Challenge and Shapiro's measurement

Hypothetico –deductive model

- Hypotheses are verified by the conclusions to be drawn from them;
- Empirical Success is accurate prediction

Newton's methodology adds to basic H-D

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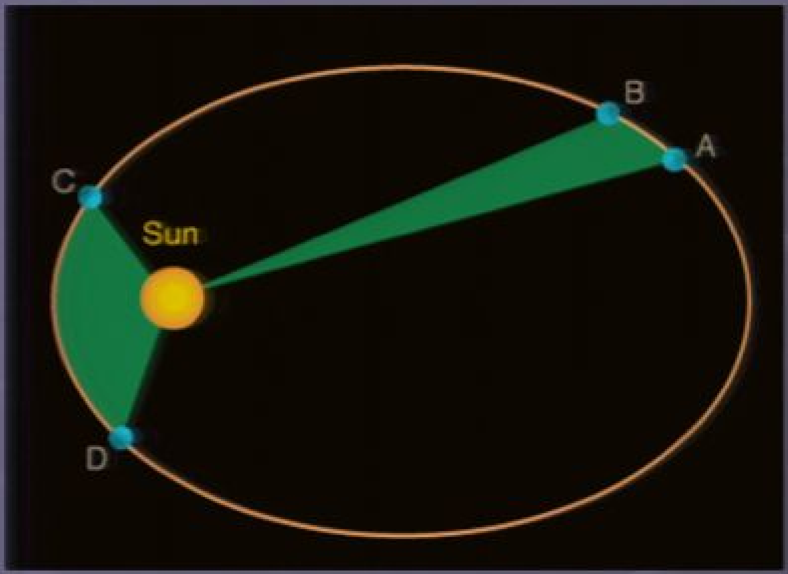
- ***Acceptance***
  Provisional acceptance of theoretical propositions as guides to research.

- All three come together in a method of successive approximations that informs applications of universal gravitation to motions of solar system bodies.
- On this method deviations from the model developed so far count as new *theory mediated* phenomena to be exploited as carrying information to aid in developing a more accurate successor.

Newton's Classic Inferences from Phenomena

- Kepler's area law $\Rightarrow$ centripetal force
- Kepler's harmonic law $\Rightarrow$ inverse-square force
- Absence of precession $\Rightarrow$ inverse-square force

Kepler's Area Law Phenomenon



- ***Kepler's 2nd law:***

  Rate at which area is swept out by radii drawn to the center is constant.

Area Law Measures Direction of Force

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- ***Principia*, Bk 1 Proposition 1**
  centripetal force ⇒ rate constant

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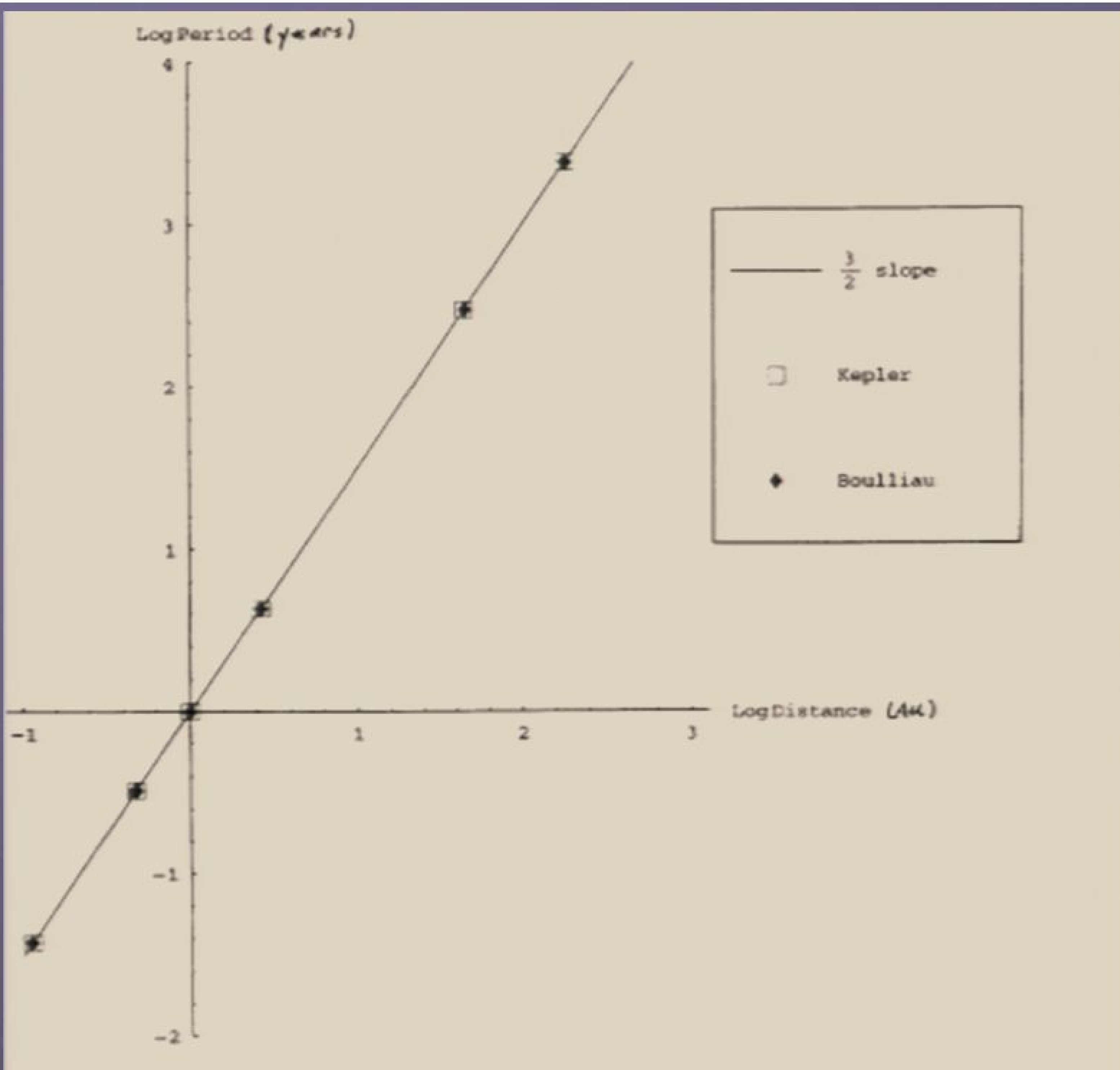
Area Law Measures Direction of Force

- ***Principia*, Bk 1 Proposition 1**
  centripetal force $\Rightarrow$ rate constant
- **Proposition 2**
  rate constant $\Rightarrow$ centripetal force
- **Corollary 1**
  rate increasing $\Rightarrow$ force off-center forward
  rate decreasing $\Rightarrow$ force off-center backward

Kepler’s Harmonic Law

- Planet’s period squared is proportional to distance from sun cubed



Log Period (years)
4
3
2
1
-1
-2
-1
1
2
3
Log Distance (AU)
3/2 slope
Kepler
Boulliau

Harmonic law measures Inverse-square law

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- Bk 1 Prop 4 Corollary 7

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- *Corollary 6*

$$T \propto R^{3/2} \Leftrightarrow F \propto R^{-2}$$

Harmonic law $\Leftrightarrow$ Inverse-square force

Systematic Dependencies

- Corollary 7

$$T \propto R^{s} \Leftrightarrow F \propto R^{1-2s}$$

Alternative phenomena	Alternative power law
$s > 3/2$	$1-2s > -2$
$s < 3/2$	$1-2s > -2$

Absence of Precession

But now, after innumerable revolutions, hardly any such motion has been perceived in the orbits of the circumsolar planets. Some astronomers affirm that there is no such motion; others reckon it no greater than what may easily arise from causes hereafter to be assigned, which is of no moment in the present question.

Newton, *System of the World* (sec. 12)

Newton's Precession Theorem

***Principia* Bk 1 Prop 45 Cor 1**

For a power-law force,

$$p^\circ \text{ precession/revolution}$$

$$\Leftrightarrow$$

$$F \propto R^n, \text{ where } n = \left(\frac{360}{360+p}\right)^2 - 3$$

Another systematic dependency

Alternative phenomena	Alternative power law
$p < 0$	n < -2
$p > 0$	$n > -2$

From the "Copernican Scholium"

By reason of the deviation of the Sun from the center of gravity, the centripetal force does not always tend to that immobile center, and hence the planets neither move exactly in ellipses nor revolve twice in the same orbit. There are as many orbits of a planet as it has revolutions, as in the motion of the Moon, and the orbit of any one planet depends on the combined motion of all the planets, not to mention the action of all these on each other. But to consider simultaneously all these causes of motion and to define these motions by exact laws admitting of easy calculation exceeds, if I am not mistaken, the force of any human mind.

Shortly after articulating this daunting complexity problem, Newton was hard at work developing resources for dealing with it by successive approximations.

Newton’s Rule 4

- In experimental philosophy, propositions gathered from phenomena by induction should be considered either exactly or very nearly true notwithstanding any contrary hypotheses, until yet other phenomena make such propsoitions either more exact or liable to exceptions.

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- This rule should be followed so that arguments based on induction may not be nullified by hypotheses.

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- Acceptance (subject to correction), rather than just assigning high probability

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- Acceptance as approximation

cf. Shimony on commitment

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i. Within the domain of current experimentation *h* yields almost the same observational predictions as the true theory;

ii. The concepts of the true theory are generalizations or more complete realizations of those of *h*;

iii. Among the currently formulate theories competing with *h*, there is none that better satisifies conditions (i) and (ii).

Newton's rejection of "mere hypotheses"

What distinguishes "propositions gathered from phenomena by induction" from "mere hypotheses"?

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- “Mere hypothesis” = something that does not realize this ideal of empirical success sufficiently well to count as a serious rival.

Precession revisited

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- Mercury precession: 573″/century
  - 530″/century due to Newtonian perturbations
  - 43″/century not explainable by Newtonian gravitation (Newcomb, 1882)

Hall's hypothesis (1894)

- "Applying Bertrand's formula to the case of *Mercury* I find, taking Newcomb's value for the motion, or 43°, that the perihelion would move as the observations indicate by taking n = -2.00000016."

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- Formula Hall appeals to is equivalent to Newton's (Valluri, Wilson, Harper, *Journal of History of Astronomy*,xxviii, 1997)

Brown (1903)

If the new theoretical values of the motions of the Moon's perigee and node are correct, the greatest difference between theory and observation is only 0°.3, making $\delta <$ .00000004. Such a value for δ is quite insufficient to explain the outstanding deviation in the motion of the perihelion of *Mercury.*

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. . . It appears, then, that this assumption must be abandoned for the present, or replaced by some other law of variation which will not violate the conditions existing at the distance of the Moon.

Einstein 1915

- GR accounts for residual precession of Mercury

"The calculation yields, for the planet Mercury, a perihelion advance of 43″ per century, while the astronomers assign 45″ ± 5″ per century as the unexplained difference between observations and the Newtonian theory."

The first result was that his theory explains ...quantitatively... the secular rotation of the orbit of Mercury, discovered by Le Verrier,...without the need of any special hypotheses.' This discovery was, I believe, by far the strongest emotional experience in Einstein's scientific life, perhaps in all his life.

Nature had spoken to him. He had to be right. 'For a few days, I was beside myself with joyous excitement' . Later, he told Fokker that his discovery had given him palpitations of the heart. What he told de Haas is even more profoundly significant: when he saw that his calculations agreed with the unexplained astronomical observations, he had the feeling that something actually snapped in him....

Pais, *Subtle is the Lord…*

GR *vs.* Newtonian Gravity

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- On *Newton's own ideal of empirical success*, GR outdoes Newtonian gravity:
  - Newtonian limit of GR recovers empirical successes of Newtonian theory
  - GR overcomes precession anomaly
  - GR adds, *e.g.* new agreeing measurement of mass of the sun

Kuhn on methodological shifts

Like the choice between competing political institutions, that between competing paradigms proves to be a choice between incompatible modes of community life. Because it has this character, the choice is not and cannot be determined merely by the evaluative procedures characteristic of normal science, for these depend in part upon a particular paradigm, and that paradigm is at issue.

When paradigms enter, as they must, into a debate about paradigm choice, their role is necessarily circular. Each group uses its own paradigm to argue in that paradigm's defense.

The Structure of Scientific Revolutions

Brans-Dicke alternative to GR (1961)

- Inspired by Mach, introduces parameter ω to represent contribution of distant stars to local curvature of space

$$\gamma = \frac{1+\omega}{2+\omega}$$

- γ = space curvature/unit rest mass
- GR: γ = 1 (*i.e.*, $\omega \to \infty$).

Discke & Goldenberg (1966)

- Solar oblateness observations suggest that about 4″/century of Mercury's precession is due to Sun's rotation

- Brans-Dicke theory with $\omega \approx 5$ would do better than GR

Shapiro radar time delay (1968-79)

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- Measures

$$\gamma = 1 \pm 0.002$$

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$$\omega > 489$$

Shapiro radar time delay (1968-79)

- Measures

$$\gamma = 1 \pm 0.002$$

- *Or,*

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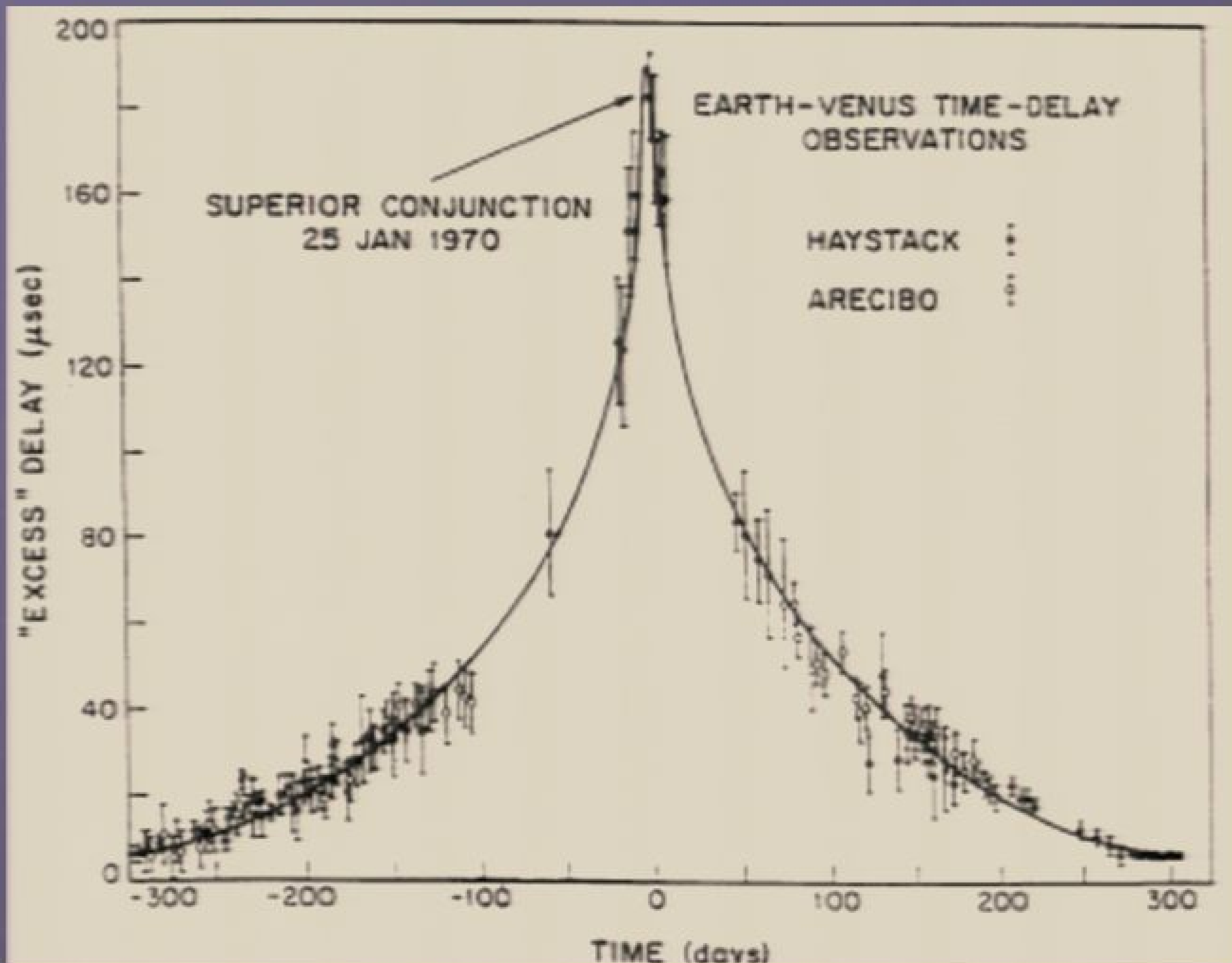
- Brans-Dicke cannot simultaneously accommodate Mercury perihelion ($\omega \approx 5$) and Shapiro delay ($\omega > 489$)


EARTH-VENUS TIME-DELAY OBSERVATIONS
SUPERIOR CONJUNCTION 25 JAN 1970
HAYSTACK
ARECIBO
"EXCESS" DELAY (μsec)
200
160
120
80
40
0
-300
-200
-100
0
100
200
300
TIME (days)