a. After inserting six sentences into the middle of Article 23 arguing that the action has to be between bodies, Newton gives up on the entire Article, cancelling it in its entirety

b. Nothing akin to this Article appears anywhere in the first edition of the *Principia*; in the second edition he added the thought experiment about parts of the earth attracting one another

5. These Articles from *Liber Secundus* thus suggest that Newton was led into his universal gravity among all particles of matter -- and the related claim that gravity toward celestial bodies is compounded out of gravity toward their individual parts -- by the question of how motions of the satellites of Jupiter could be so regular when that of our moon is not

   a. For, that left him concluding that the action of the sun on Jupiter and its satellites must be virtually the same, and hence independent of the quantities of matter in them

   b. And that makes sense as a form of causality only if there is an action between the matter of the sun and the matter in each of them, an likewise between the earth and bodies on and near it

   c. And then more generally, only if all matter interacts in accord with the law of gravity

6. Regardless, Newton always claimed that he did not arrive at universal gravitation by leaping to it as a hypothesis, and the line of reasoning I am proposing, starting with the Copernican scholium, does let it emerge in a step-by-step fashion, in response to a sequence of naturally arising questions

   a. Universal gravity, far from being a bright idea, involves a sequence of (at the time) ever more implausible claims (see Appendix), including ones not only beyond all available empirical evidence, but as well beyond the bare law

   b. And the law itself was reached only under the assertion lifted from the definition of *pondus* that weight varies as the product of *pondus* (=*mass*) and centripetal change of motion

7. Notice how immense the burden of empirical proof has become versus what it was in either version of De Motu (see Appendix); this was the burden to which I claim the *Principia* was a response

V. Toward an Emerging Conception of Science

A. The Conception of Evidence in De Motu Version 1

1. The different versions of De Motu present us with a sequence of contrasting views about the kind of evidence that can be developed out of observations

   a. The sort of claim that can receive strong evidential support from observations, and the amount of support it can receive

   b. The extent to which conclusions from the evidence have to be qualified because of inexactitudes of observation

   c. The conclusions that can be drawn from any discrepancies between theory and observation

2. Version 1 has the promise of supporting extremely strong conclusions about Keplerian motion being exactly true, or exactly true save for various secondary effects

   a. Licenses the conclusion that e.g. other trajectories within observational accuracy no longer need be considered as viable alternatives (and other ratios besides exactly 3/2)

    b. Licenses the conclusion that Keplerian motion, including the area rule, basic, and that any deviations should be viewed as superposed secondary effects
  3. Version 1 allows strong conclusions to be drawn from any systematic discrepancies between observations and theory
    a. Prima facie, some force besides the dominant inverse-square centripetal force is at work
    b. Can therefore use discrepancies as basis for characterizing these forces, if not for constructing a theory of them -- i.e. discrepancies provide answers to questions about these forces
    c. Of course, if no coherent characterization as forces, then in a position to draw one of two other conclusions
      (1) A systematic error in observation, again amenable to characterization via the discrepancies
      (2) Or a false theory, requiring modification that can be characterized via the discrepancies
    d. Notice that such inferences, including the last one, can be drawn from even very small systematic discrepancies; this is what I mean by an improvement in the quality of evidence
  4. Can thus think of Version 1 as focused on the issues of the perfectibility of astronomy and the true motions of the five planets around the sun -- the other major issue arising out of the skeptical doubts toward astronomy to which Kepler was replying in his unpublished *Apologia*
    a. Newton had never shown much interest in these issues in the 1660's and 1670's, presumably because he was unaware of how much attention was being given to it in some circles
    b. Perhaps his first conversation with Halley made him aware of it, and this can then account for his change in attitude about the importance of his 1679 "calculation" of the ellipse
    c. Would dovetail with the interest he had previously shown in issues concerning the perfectibility of empirical science generally -- e.g. in his interest in adding resistance effects to projectile motion, not to mention his remark about “science” in his Optical Lectures of the early 1670s
  5. Version 1 compatible with two different views of the "perfectibility" of empirical science -- i.e. with two different views about the treatment of secondary effects
    a. On the one hand, may just be able to characterize them empirically, thus licensing stronger conclusions about the primary mechanism by permitting empirical corrections of observations
    b. Or may be able to develop a theory of secondary mechanisms, thus opening the way to pursuing truly exact science
    c. Ambiguity between these two most clear in the proposed treatment of resistance in Version 1

B. The Conception of Evidence in Version 3
  1. With Version 3 get a shift from the issues of the perfectibility of orbital astronomy and the true motions of the planets around the sun to the issue of empirically resolving, once and for all, the issue of the world systems
    a. Version 3 provides the strongest empirical proof yet for Copernicanism, a concern at most in the background in Version 1

b. But at the price of losing many of the conclusions about the perfectibility of orbital astronomy

2. If concede that calculating the actual orbits is beyond the capacity of the human intellect, then can no longer draw such strong conclusions from any discrepancies between observation and theory
   a. Given a discrepancy, limited basis for concluding that it is from (1) celestial body interactions, (2) some other mechanism, (3) systematic observational error, (4) a false underlying theory
   b. Thus little if any hope of carrying science to a higher level of perfection than that achieved in Version 3, it would seem
3. The conclusions that can be reached about Keplerian motion as the basic ideal are therefore much tenuous, and hence in jeopardy, than with Version 1
   a. More room now for arguing for e.g. other alternative trajectories within observational accuracy, and hence for arguing that Keplerian maybe not the basic ideal
   b. Conclusion about Keplerian as "mean" open to a predominately "instrumentalist" interpretation in the absence of showing that it is strictly speaking the mean
4. Little if any possibility of developing a theory of secondary effects from discrepancies between observations and theory if motions really beyond human capacity to calculate
   a. Can still characterize discrepancies, but only in the form of an approximate empirical characterization
   b. I.e. can characterize them in order to argue that they are attributable to various secondary effects, and hence are compatible with the conclusion that observations are compatible with theory (ignoring certain secondary effects)
   c. Thus in a way can characterize discrepancies to allow corrections of observations, but not precise corrections
5. In other words, the sort of evidential argument that can be run off observations, given Version 3, is fully akin to that which Huygens and rational mechanics was committed
   a. No exact science of secondary effects, hence no exact science
   b. But still can develop empirical arguments that allow one to conclude that observation fully compatible with theory, once theory interpreted as making claims about idealized
   c. And in some cases may be able to characterize or neutralize secondary effects sufficiently to draw some stronger conclusions from discrepancies -- e.g. Huygens and center of oscillation

C. Intimations of a New Conception of Evidence

1. If the view of evidence implicit in Version 3 were the best that we could hope for, then the proposal for universal gravitation would have much the same status as Descartes' vortex theory
   a. A philosophical conjecture that is compatible with observation, at least up to the extent to which we can meaningfully compare observation and theory
   b. But still primarily a philosophical conjecture, different from Kepler's proposed mechanisms mostly in how sweeping it is

2. But if can conclude that no other mechanisms at work in the orbital system, then perhaps can develop stronger evidence for universal gravity by showing that deviations from Keplerian motion are attributable to it -- just the sort of evidence Newton seemed to be pursuing in correspondence with Flamsteed, especially in question of Jupiter's effect on Saturn
    a. I.e. then perhaps a stronger conclusion than just that the actual motions do not confute universal gravity
    b. For evidence that all celestial bodies attract one another in accord with universal gravity
    c. This via an argument that deviations from Keplerian are fully consistent with such gravitational interaction, coupled with argument that no other mechanism producing any deviations
3. Two possible ways in which such a more ambitious line of evidential reasoning can be developed, one of them stronger than the other
    a. Perhaps can only show that universal gravity offers the best explanation of the deviations from Keplerian motion by showing that it explains, at least to a high degree of approximation, the actual deviations
    b. Or can show that universal gravity fully accounts by showing that the actual deviations can be derived from universal gravity to within observational accuracy
4. Either way, back to an at least qualified version of the "perfectibility" of orbital astronomy, for even if cannot achieve an exact science of the motions, can still reach strong conclusion about what mechanisms are at work
    a. I.e. in much the same position with respect to orbital astronomy as projectile motion with resistance, for can at least give approximate characterization of second-order effects
    b. And this sufficient to draw strong conclusions about mechanisms
5. Goal here should be contrasted with that which *Principia* ultimately faces, for an empirical defense of universal gravity is one thing, and an empirical defense of the conception of physics announced in the Preface to the First Edition is quite another
    a. That conception -- all physical processes from a few fundamental forces acting among ultimate particles of matter -- an alternative to the mechanical philosophy
    b. Empirical defense of it calls for truly exact science

D. An Evolution in Conceptions of Evidence

1. Entire course can now be seen as an evolution in conceptions of what can be done with empirical evidence -- an evolution starting with Copernicus and Tycho and still proceeding as Newton starts writing the *Principia*
    a. Copernicus raised the issue and proposed the idea that a better theory would yield better agreement with observation
    b. But Tycho was the first to push the idea that pursuing precise agreement between observation and theory was a means of empirically resolving issues in astronomy

2. Kepler added the idea that some issues in astronomy were going to be resolved only through identifying the physical processes governing planetary motion
    a. And with it added the idea of inferring underlying physical processes from the exact motions, so that pursuit of exactitude became a vehicle for drawing strong conclusions about physics
    b. But insufficient constraints from a general mechanics of motion undercut the strength of his inferences
3. Galileo and Descartes, along with others, began forming such a general mechanics of motion, but under a conception of empirical evidence in which they abandoned all hope of a truly exact science, instead resorting to an exact science of an idealized situation
    a. Principal conclusion from empirical evidence: theory fully compatible with, and hence burden of proof on anyone who wants to propose an alternative theory
    b. But limited empirical grounds for drawing inferences about underlying mechanisms; need either independent philosophic basis, or need to qualify conclusions about underlying mechanisms
4. With Huygens get a more ambitious conception of empirical evidence, for pursuit of precision can yield conclusions about second-order effects, if not second-order mechanisms, in certain suitable cases, as illustrated by his solution for the center of oscillation
    a. Cases in which theory allows experimental paradigms in which such second-order effects as resistance either neutralized or characterizable
    b. Conclusions of the sort that *g* not everywhere the same, but subject to small variations
    c. Much tighter constraint then on Kepler-like reasoning to underlying mechanisms, as illustrated in Huygens's evidential arguments for his theory of gravity
5. Finally with Newton see pursuit of some sort of empirical "proof" of basic claims in physics, pursuit of goal of something stronger than hypothetico-deductive evidence for claims about physics, a conception that he had first announced in his work on optics in the early 1670s
    a. "Proof" that would justify disregarding the possibility of alternative hypotheses equally in conformity with observation
    b. And hence of truly being able to settle issues of underlying physics comparatively definitively on empirical grounds

E. Parallel Evolution in the Science of Orbital Motion

1. Four initial steps that freed orbital astronomy from the millennium and a half Ptolemaic tradition:
    a. Copernicus's challenge that retrograde motion mere appearance
    b. Tycho's body of positional observations of uniform quality
    c. Galileo's telescopic observations, showing among other things how much less was known than had been thought
    d. Kepler's reforms, culminating in the *Rudolphine Tables* and a wholly new preoccupation with being able to calculate locations within observational accuracy

2. Steps before 1650 toward a science of the mechanics of motion of comparable quality to the mechanics of phenomena of static equilibrium
   a. Galileo's formulation of a mathematical science of select motion under uniform gravity along parallel lines, achieved by idealizing the motion to be free of resistance
   b. Descartes' emphasis on the *conatus* to recede from the center in curvilinear motion and the consequent need for an outside impediment or force in all curvilinear motion
3. Huygens's building on the mathematical theory of Galileo and Descartes' *conatus*
   a. Specifically, by extending Galileo's fragment of motion under "Galilean" gravity to include pendular motion of forms determined by evolutes
   b. And developing Descartes' idea into a mathematical theory of uniform circular motion and centrifugal force
4. Prompted by Hooke, Newton's discovery that the mathematical theory of uniform circular motion can be generalized into a mathematical theory of motion under centripetal forces -- i.e. motion in which the area rule holds
   a. In the registered version of De Motu, linking Kepler's three "laws" together through inverse-square centripetal forces toward the Sun, Jupiter, etc.
   b. And then taking the further step in Version 3 of allowing for the interaction between centripetal forces directed toward different bodies and having to face the problematic ramifications of this
5. One can think of the list of ten advances (see Appendix) as milestones toward Newton's *Principia* and the Newtonian Revolution even though a great deal remained to be done between it and them

F. Three 17th Century Revolutions in Evidence
1. Overall course offers grounds for claiming that the scientific revolution reflected in those ten milestones involved a revolution as well in views about what can ultimately be achieved via empirical evidence
   a. A revolution in conception of how to marshal data into evidence, and hence in conception of how to make the most of evidential reasoning
   b. From naive Aristotelian (and Ptolemaic) view of saving the phenomena to a view under which empirical world provides clear answers to questions
2. First revolution was the commitment to the idea that the empirical world ought to be the ultimate arbiter in matters of natural philosophy
   a. The aspect of the scientific revolution that is most widely recognized, in large part because it is the most pervasive, stretching from Copernicus through Newton, and even including Descartes
   b. But not the aspect that is responsible for distinguishing modern science from science before the scientific revolution
3. Second revolution came from the realization that higher quality empirical evidence can be achieved through theory-mediated evidence -- through theory being a vehicle for turning data into evidence

a. First indication of this from Kepler's use of deviations from a first-order theory as evidential basis for second-order refinements and conclusions about underlying mechanisms
b. Second indication from Galileo's realization that a network of theory opens the way to designing more telling experiments and from Descartes' realization that theory is crucial to eliminating the ambiguity of what the world is telling us
c. But fullest realization of the use of theory as an instrument in marshalling evidence comes with Huygens and rational mechanics, both in his measurements of the distance of fall in the first second and in his solution for the center of oscillation

4. Third revolution in conceptions of evidence is the one I prefer to call the "Newtonian revolution", achieved through the *Principia*
    a. Pursuit of exact agreement between theory and observation as a means of reaching very strong conclusions about underlying physical processes and mechanisms
    b. More specifically, the demand that every discrepancy between theory and observation be taken as telling us something that we must pursue until we establish what its source is
    b. First glimmers of this revolution in the various versions of De Motu and the work in their wake
    c. Something Newton discovering in 1684/85, on my view; not something he had formed earlier, his remark about "natural science supported by the greatest evidence" notwithstanding
5. The third of these revolutions is the most important, I claim, for it is what really distinguishes modern advanced science and is responsible for its extraordinary epistemic achievement
    a. It is the least understood of the three, and hence ultimately requires the most discussion -- why we are continuing to a second semester
    b. But the unfolding vision of it, I claim, is what drove Newton on to the full *Principia*, though when this vision became clear, even as a possibility, is unclear
    c. Given the evolution of the *Principia* itself, perhaps not until well into 1685, if not later
6. And what lies behind this vision is his own perception that universal gravitation is not a mere hypothesis, but is instead something he basically established as a "scientific" fact by deducing it from phenomena of motion out of the theory of motion initiated in De Motu

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