b. Appeal to pendulum experiment without much explanation of why it shows what he claims for it

c. Motive force producing motion of the pendulum is gravity, with resistance forces the same when velocity the same, and motion produced is a product of quantity of matter and change in velocity

d. If quantity of matter were not strictly proportional to weight, pendulums of the same weight, but with different materials inside identical bobs should (or might) display different motions

e. (Reasoning should be considered in the light of Descartes' analysis of the relationship between weight and quantity of matter)

4. Question: what considerations are leading him to draw the distinction here, but not in De Motu Versions 1 and 3?; here is one possibility

   a. The pivotal conclusion in the "proof" of Copernicanism was that $C_h/C_j = r_j/r_h$, for this was the basis for reaching a conclusion about r_h

   b. But the point to which these radii are referred is a "center of gravity", so that $W_j*r_j = W_h*r_h$, where the *W*'s refer to what the Sun and Jupiter would weigh at the surface of the earth

   c. In other words, $C_h/C_j = W_h/W_j$

   d. But their weight at the surface of the earth is a parochial quantity; we want a quantity that they have everywhere, independently of being at the surface of the earth, and that would yield their weight at this surface

5. By the reasoning that distinguishes the three quantities of centripetal force and justifies the claim that the quantity of matter is proportional to the weight, can now relate the absolute force to a non-parochial quantity: $C_h/C_j = M_h/M_j$, where M represents the quantity of matter

   a. But Newton is doing more than just this, for, by virtue of the pendulum experiment, he is also tying this non-parochial quantity to the resistance a body displays to changes of motion

   b. And hence to bulk (*moles*) in impact, "apart from considerations of gravity"

E. The Law of Gravity Emerges

1. With the distinction of what he later came to call *mass* and the relation $C_h/C_j = M_h/M_j$, now have the law of gravity staring us in the face

   a. Centripetal acceleration at any point is proportional to $C/r^2 = M/r^2$

   b. Force is proportional to change in motion and hence to Mm/r^2

   c. Therefore, forces must be equal, via symmetry, yielding the third law as well, this time holding for mutually interactive centripetal forces, and not just forces in impact

2. Alternatively, Newton might have reached law of gravity by first using the second law to conclude that the force on each body is proportional to its mass, the *C* of the other, and inversely proportional to the square of the distance between them

   a. He could then have invoked the third law to equate these two forces, allowing him to conclude that their respective *C*'s are proportional to their masses (as he does in the *Principia*)

   b. My guess is that he played different ways off against one another (as in the Appendix)
3. Furthermore, we have before us a line of reasoning that leads to *universal* gravitation:
   a. The absolute quantity of force depends on the quantity of matter in the body at the center, so that if any of that matter were taken away, the absolute force would diminish
   b. Unless the absolute force is a non-extensive, "emergent" property of the total matter forming the body, then each part of the absolute force must be associated with a part of the total matter
   c. I.e. each particle of matter forming the central body must have a centripetal attraction associated with it in such a way that the total centripetal attraction results -- is compounded out of -- from the net effect of all the particles
   d. But, in the absence of having any reason to think that the matter forming the celestial bodies is distinctively different from other matter, can generalize to claim that all matter has such a centripetal attraction to it
4. This line of reasoning from the "proof" of the Copernican system to universal gravity has a number of lacunae in it, especially when considered in the light of its rather extraordinary conclusion
   a. Chief among these is the claim that the attractive characteristics of a celestial body do not arise as an "emergent" property of the matter forming it
   b. The obvious way of responding to this lacuna is to show that the attractive characteristics of the body can arise from the combined effects of the individual particles of matter
   c. Newton shows this in the *Principia*, and in a letter to Halley in 1686 remarks that he did not have a complete argument for universal gravity until he had shown it (in the spring of 1685)
5. The putative line of reasoning extending from the "proof" of Copernicanism to universal gravity yields a conclusion that has a much greater burden of proof on it than Copernicanism has
   a. Not only does action at a distance violate the dictates of the mechanical philosophy, but now endowing matter generally with a new seemingly occult property, *attraction*
   b. Obvious question: what possibilities are there for developing evidence to meet this burden?

F. Toward Universal Gravity: Weight $\propto$ Inertial Mass

1. My proposal for how the law of gravity emerges hinges on an elaborate experiment Newton carried out during the spring of 1685, but it does not explain what prompted him to carry it out
   a. The conclusion drawn from the experiment amounts to saying that, in the absence of other forces, gravity always produces the same change of motions in all bodies, regardless of their weight, shape, and the material composing them
   b. But this was a claim from Galileo and Huygens that was universally accepted
   c. So, why take the trouble to carry out such an experiment
2. Another manuscript gives us what appears to be the best clue, Newton's original version of his "System of the World," entitled *De Motu Corporum, Liber Secundus*

a. Written in what Newton later called "the popular style," namely the same style as Descartes' *Principia*, with numbered article and postils in the margin (see Appendix)
b. Fifty-six page, eighty one Article draft in Humphrey Newton's hand, dating from spring and summer of 1685, heavily re-worked by Newton himself at more than one later stage
c. By virtue of its being complete instead of a mere fragment, its paralleling Book 3 of the *Principia*, and its including so many modifications made by Newton, it is the most informative manuscript we have from while Newton was developing the *Principia* in 1685

3. After concluding that the centripetal forces toward the sun, Jupiter, Saturn, and the earth vary inversely with the squares of the distances from them, Newton turns to the question of other quantities with which these forces vary
   a. Article 18 (see Appendix) concludes that the 3/2 power rule could not hold, nor the regularity of the motions of the satellites of Jupiter, unless the centripetal action of the sun on all these bodies is proportional to the quantity of matter in them
   b. For only then, for example, could Jupiter and its satellites experience essentially the same centripetal acceleration toward the sun
   c. That Newton would worry about this may reflect Flamsteed's question about why the motions of those satellites are so regular, while the motion of our moon is not
4. Notice too that Newton's subsequently deleted all but one of the occurrences of the word *pondus* in Article 18, replacing them not with *massa*, but with different phrases amounting to quantity of matter
   a. Presumably did this because of need for the word to mean *weight* at the one place, and leaving the other occurrences in place produced quite an ambiguity
   b. Nowhere in *Liber Secundus* does *massa* occur, but only later
5. The very next Article (see Appendix) then describes the experiment, in more detail than anywhere else including the *Principia*, showing that *weight* is proportional to *quantity of matter*, with the number of the Proposition that licenses the conclusion to be filled in later
   a. Claim: demonstrated this relationship more precisely than anyone theretofore had
   b. In *Principia* claims to within 1 part in 1000
   c. By the beginning of the 20th century, had been shown to within 5 part in 100 million
   d. Notice too the deletion at the end of this Article, dropping the idea of using *weight* or *heaviness* to denote quantity of matter
6. The suggestion then is that Newton performed this experiment to confirm that some centripetal forces -- in particular, terrestrial gravity -- do act equally on all bodies at any one location
   a. In Einstein's hand this became known as the (weak) equivalence principle, asserting the equivalence of gravitational mass with inertial mass
   b. In Newton's hand, it asserts only that the magnitude of gravitational forces varies with the inertial mass of the bodies on which they act

G. The Law of Gravity: Interaction vs.Force

1. Article 20 (see Appendix) then cites the third law of motion to justify the conclusion,

   > And since the action of centripetal force upon the attracted [*attractum*] body, at equal distances, is proportional to the matter in this body, it is also reasonable to grant [*rationi etiam consentaneum est*] that it is proportional as well to the matter in the attracting [*trahene*] body. For the action is mutual, and causes the bodies by a mutual endeavor [*conatu mutuo*] (by law 3) to approach each other, and accordingly the action in one body must necessarily be in conformity with the action in the other.

   a. In other words, the magnitude of the centripetal force in question is proportional not only to the quantity of matter in the body on which it acts, but also to the quantity of matter in the body toward which the other is drawn

   b. Notice here that the mutuality of the action and the applicability of the third law is simply asserted; nothing earlier in *Liber Secundus* has provided warrant for this

2. What is left unsaid but appears to be motivating Article 20 is a somewhat paradoxical aspect of the conclusion that the centripetal forces toward the sun and earth act on bodies in proportion to the quantities of matter in them

   a. According to what later became known as the law of inertia, these forces act as external causes, as a consequence of which their motion becomes curvilinear

   b. But how can the same external cause adjust itself to the body on which it acts at any location?

   c. The proposal in Article 20: "One body can be considered as attracting and the other as attracted, but this distinction is more mathematical than natural"

3. Article 21 (see Appendix) then goes on to elaborate this last idea rather clumsily, with redundancy that suggests Newton is struggling with how to make the point he is trying to make

   > And hence it is that the attractive force [*vis attractiva*] is found in both bodies. The sun attracts [*trahit*] Jupiter and the other Planets, Jupiter attracts its Satellites and similarly the Satellites act on one another and on Jupiter, and all the Planets act on one another. And although, in a pair of Planets, the action of each on the other can be distinguished and can be considered as paired actions [*actiones*] by which each attracts [*trahi*] the other, yet inasmuch as these are actions between two bodies, they are not two but a simple operation between two termini.

   a. In other words, the forces in question are not really external causes that adjust themselves to the bodies on which they act, but a single mutual action between the bodies

   b. Notice now how Newton is making a claim for which he has no empirical evidence, but instead making it in response to a conceptual worry tied to the notion of cause

   c. Nothing remotely akin to Article 21 occurs anywhere in any edition of the *Principia*

4. The very next Article attributes our inability to perceive such mutual gravitational interaction to the attractive forces being too small, followed by a long, heavily reworked Article in which Newton tries to justify the claim that such interaction takes place among all terrestrial bodies

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)