C. A New Fundamental Question About Planetary Motion

1. When Kepler originally argued that astronomy is a part of physics, he was insisting not only that physics resolve the dispute among the systems, but that it also settle questions about the precise trajectories of the planets and the moon
   a. From the point of view of the second of these demands, the planetary mechanics of Descartes' vortex theory shifts to a new basic question
   b. Not why the planets go round in a regular manner or why motion itself is maintained, but why they do not go off in a straight line
2. After Descartes, the centrifugal tendency was viewed as a basic feature of all curvilinear motion, posing specific as well as general questions
   a. Why curvilinear at all takes priority over other questions
   b. An end to Platonic perfect circles requiring no explanation
   c. Why specific curvilinear trajectory becomes secondary, to be answered via some specific variation on the answer to the first
3. Descartes contrasts with Kepler here, who in no way addressed the question of why curvilinear rather than straight
   a. Main "anti-centrifugal" element in Kepler involves a varying force of attraction needed for an ellipse rather than a circle
   b. Obvious post-Cartesian move: let this force be responsible for curvilinearity generally (for Keplerian flux driving planets will not do the job since it is not perpendicular to the motion)
4. Impact: those concerned with physics of planetary motion became more preoccupied with the mechanism responsible for curvilinear trajectory than with the mechanism dictating the specific oval
   a. Indeed, they were even comfortable posing this basic question for circular orbits
   b. In the process letting second-order effects or variations in basic mechanism account for deviations from circularity
5. Another question that becomes more important because of Descartes' vortex theory is whether our solar system is stable at all
   a. Kepler worried about the perfectibility of planetary astronomy, and not about basic question of stability
   b. But, given Descartes' account of how the centrifugal tendency is balanced, appropriate to ask about radical changes in motion of the planets
   c. And the account of the death of stars and vortices adds all the more reason to ask this question

D. The Implicit Challenge to Kepler's "Laws"

1. Even without the stability issue, Descartes' vortex theory raises serious questions about Kepler's "laws" -- specifically, about their nomologicality, their character as approximations, and their range of application

"We must not think that ... the circles [the planets] describe are absolutely perfect; let us instead judge that, as we see occurring in all other natural things, they are only approximately so, and also that they are continuously changed with the passing of the ages." [34]

"... But, a few centuries from now, all these things will be observed to have changed from the way in which they are now" [36] -- pertaining primarily with precession of aphelia

"For, inasmuch as all the bodies in the universe are contiguous and act on one another, the movement of each is affected by the movements of all the others and therefore varies in innumerable ways." [157]

2. One question here is whether Keplerian motion is ever compatible with Descartes' vortices
    a. Descartes never addresses this as such, though he does specify several Keplerian features, like non-circularity and the way Kepler handles latitudes, in Articles 34-37
    b. But he does leave more than enough room by granting non-circularity and satisfying the basic phenomena with regard to periods and distances
    c. Still, no specific account of the area rule or of elliptical trajectories (nor of the 3/2 power rule), so that the question whether the vortex theory is compatible with Kepler is left somewhat open
3. A different question: could Keplerian motion be a mere epochal curiosity or parochialism, so that different ovals and velocity rules will hold in the future
    a. Even if Kepler's account highly correct for the motion at the time, Descartes' vortex theory offers no mechanism underlying it, and hence offers no reason to think Kepler's generalizations should be taken to be nomological
    b. Worse, deviations from these generalizations are to be expected, given the analogy with fluid vortices, which assume all sorts of varying shapes [30]
4. One implication of the vortex theory, then, is that no special significance should be attached to Kepler's first two "laws"
    a. They are not a basis for inferences about the underlying physics
    b. They are not even a basis for distinguishing primary from second-order effects
    c. In short, the vortex theory undercuts their evidential value entirely
5. An added worry: even independently of the above considerations, there is no reason to regard the 3/2 power rule as a general feature of orbital systems
    a. The period-distance relation is peculiar to the "pressure" field and to densities of the planets
    b. So, even if it holds for our system, there is no reason in the physics for why it should hold for other orbital systems
    c. That is, Descartes' theory entails that Kepler's 3/2 power rule is an accidental feature of our system -- just as Kepler's account of this rule does
6. The impact of all of this, in some circles, was much less interest in the exactitude of Kepler's laws and in what can be learned from them than Kepler had thought appropriate

a. Of course, others had fed this tendency -- Galileo's remarks on the accuracy of the orbits in the "Fourth Day" of the *Dialogue*, and Kepler's remarks in the Preface to the *Rudolphine Tables*
b. But Descartes is pushing this line of thought much farther than either of those two did
c. As we shall see, his doing so had some consequences -- most notably for Huygens

E. A New Set of Basic Questions for Cosmology

1. The old cosmology had a limited range of questions to which it supplied answers
   a. E.g. why do all the stars remain in their relative positions, and why do the basic regular patterns of motion recur -- from Ptolemy's *Planetary Hypotheses*
   b. Descartes' vortex theory has cosmology addressing a new, radically expanded set of questions, in the process transforming the discipline
2. New questions about the origins of the cosmos and solar system, and long-range trends within both
   a. For Descartes it is fair game to speculate about origins, for once the world is set in motion, it takes its own course
   b. Speculation here consists of inference back to possible origins -- conceptually possible and compatible with the current state
   c. Equally, inferences forward to possible long-term futures
3. Questions about physics of sun and stars, the objects that are central to the modular vortex structure
   a. How they give off light, and their role in the vortex structure
   b. The "birth" and "death" of stars -- novas and other sidereal changes
   c. The formation, propagation, and evolution of sunspots and other observed vagaries
4. Questions about the structure of the universe beyond our solar system
   a. The old question was whether all the stars were on a single sphere or in some broader region
   b. Descartes opens the way to questions about complex structures elsewhere, interacting with ours and giving light to ours
   c. What is the general structure of the (nearby) universe
5. These questions are to be addressed speculatively, via hypotheses and available empirical evidence; but still an empirical program, especially for those who regard Descartes' proposed answers as one among other possible ones
   a. As Descartes himself suggests, the combination of constraints from what is possible and what exists now, related through fundamental laws of nature, provides an adequate evidential base to make this program something other than empty speculation
   b. The set of questions and the general approach to them that he proposed has remained in the forefront ever since, framing cosmology
   c. High quality answers have been forthcoming mostly within the last 120 years, as more became known about the fundamental laws of physics and more empirical information became available through technological advances in science -- e.g. spectrometers

F. A New Evidential Standard in Physical Astronomy

1. Over a roughly 50 year period Tycho and Kepler had created a new evidential standard in astronomy, replacing the 1400 year old standard set by Ptolemy's *Almagest* and *Planetary Hypotheses*
   a. General quantitative agreement with salient phenomena, constrained by requirements of physical plausibility, no longer enough (Galileo's *Dialogue* notwithstanding)
   b. The new standard required comprehensive and detailed quantitative agreement within, or at least broaching on, observational accuracy
   c. This standard gained ascendency in the 1630's following the observed transit of Mercury and subsequent growing appreciation of just how good the *Rudolphine Tables* were
   d. Kepler added the further requirement of a plausible physics of the mechanisms underlying the detailed patterns -- this to select among competing hypotheses and to avoid being misled by observational inaccuracies
2. Descartes' vortex theory undercuts this new standard in significant ways because no value can be placed on precise agreement with observation when what is being observed is not really regular
   a. Precise agreement is not a basis for having confidence either in generalizations like Kepler's "laws" or in hypotheses about the physical processes underlying them
   b. Not only is success in the pursuit of precision not a big deal, but lack of success in this pursuit is no major cause for concern
   c. Pursuit of precision is generally not worth the effort, though there may be notable exceptions where complete explanatory theories emerge
3. Yet Descartes did not really revert to the old standard of just saving the appearances with a plausible underlying physics -- the standard that reigned throughout the Ptolemaic era
   a. He insisted on a complete unified physical cosmology, with the phenomena saved by it, and not by intermediate mathematical hypotheses standing between the physics and the phenomena in the manner of Galileo and the mathematical astronomers
   b. Strength of evidence through the range of phenomena covered by the limited physical mechanisms allowed as possible by the laws of nature
   c. In other words, through completeness constrained by simplicity -- ultimately through the completeness demand of a total unified science
4. Thus, after Descartes there were two competing evidential standards within astronomy
   a. Precision within observational accuracy for geocentric longitudes and latitudes -- adopted by most mathematical astronomers
   b. Comprehensiveness of a unified explanatory system -- adopted by various others, perhaps out of a demand for an overall cosmological picture to replace the Aristotelean one
   c. These two are not straightforwardly reconcilable -- i.e. there is no obvious way of effecting trade-offs between them!

5. These two standards have contrasting implications for how one ought to go about doing physical astronomy and other sciences: piecemeal versus global approaches
    a. Descartes challenges the feasibility of doing piecemeal science on the grounds that not enough proper evidence is going to be available to prevent being led down garden paths
    b. Piecemeal science promising only when one can proceed strictly and rigorously from basic laws, thereby safeguarding against being misled
    c. Otherwise, the only adequate constraints against being misled must come from pursuing a global account
6. This tension between two approaches to marshaling evidence for scientific theories continues to the present day

IV. Cartesian Conceptions of Empirical Science

A. Descartes' Conception of the Problem

1. Reason alone can yield certainty in geometry and other matters, but it can take us only so far toward knowledge of the material world
    a. Geometry provides certainty within the realm of possibility, and it offers a standard of rigor in reasoning
    b. But the actual world -- the one God chose -- cannot be singled out from geometrical and mathematical considerations alone

       "For, seeing that these parts could have been regulated by God in an infinity of diverse ways; experience alone should teach us which of these ways He chose." [46]

    c. The problem is how to bring empirical considerations to bear in a decisive way
2. The problem Descartes saw in turning to the empirical world is reflected in his criticisms of Galileo's *Two New Sciences*

    "He seems to me very faulty in ... never stopping to explain [*explicandae*] completely any matter, which shows that he has not examined things in order, and that without having considered the first causes of nature he has only sought the reasons of some particular effects, and thus he has built without foundation [*fundamento*]. (p. 387f of Drake)

    a. Also, the account of fall is "built without foundation, for first he should have determined what weight is" (p. 390), and the theory is incomplete since it fails to treat pendular motion (p. 391)
    b. One can easily imagine similar criticisms of Kepler's orbital theory, with complaints about the *ad hoc* physics, but even more so questions about the true regularity of the trajectories, versus their being epochal parochialisms, in the absence of proper mechanical foundations
3. The standard reading of these critical remarks (*vide* Drake) is that Descartes was unwilling to pursue a strict program of empirical science; but there is another reading: he was afraid of garden paths in empirical science
    a. He could not help but see Ptolemy as a paradigm of brilliant, yet unsuccessful empirical