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

reasoning, and he could legitimately ask how Galileo and Kepler had insured against making similar mistakes

   b. He drew the same basic conclusion that Kepler had: the only way to safeguard against such errors is to make sure that the conclusions being drawn were consistent with true physical causes

4. A strong case can be made that, not just for Descartes, but for others in the first half of the 17th century as well, a key issue was how to avoid another garden-path

5. The suggestion, then, is that Descartes' pursuit of a comprehensive causal picture may have been not so much a commitment to a program different from empirical science, as it was a view about how to do successful empirical science

   a. No empirical conclusion is secure unless it is based on a secure causal account of the relevant phenomena

   b. The problem is how to obtain a secure causal account; clearly we cannot just put forward hypotheses based on characterizations of the phenomena, for the insecurity of these characterizations is the source of the problem in the first place

6. One obvious step toward securing foundations for such a causal account is to try to establish universal principles governing all causation in the material world -- i.e. laws of nature

   a. This amounts to identifying which questions truly call for causal answers and what sort of answers to these questions are appropriate

   b. Given his views about the role of reason in "first philosophy," it was natural for him to think that these conceptual foundations could be established *a priori*, via a clear and distinct grasp of the relevant ideas

   c. Grounding empirical science on metaphysics, including metaphysics of God, seemed necessary to him, for metaphysics on the firmer footing

7. Notice, however, that some might have viewed the foundation not as lying in metaphysics and God, but instead in fundamental principles governing motion

   a. E.g., *All departures of any body from rest or from uniform motion in a straight line require an external action or force arising from some other body (in contact with it) that effects a change in motion by transferring some of its motion to the other one, with the aggregate of their total motion remaining the same before and after*

   b. Starting from a principle of this sort, viewed as an empirical claim to be supported by empirical evidence, instead of being derived from metaphysics, is the stance Regius, and various later Cartesians, adopted

B. How To Do Science: the Cartesian Solution

1. The first goal of empirical science ought to be at least a broad outline of the causal mechanisms and processes that govern phenomena, for only then will we be in a position to judge the likelihood that empirical factors are not misleading us

   a. But this is just what Aristotle tried to do, and failed
   b. The question is how to safeguard against his mistakes
2. One safeguard is to restrict the list of universal, fundamental causal mechanisms as much as possible
   a. The pursuit of clarity and distinctness of understanding is our basic resource for protecting against error; hence should insist that causal explanations yield genuine understanding -- i.e. they leave no open questions
   b. For Descartes, the mechanical philosophy can thus be viewed as a means to an end, and not something he adopted beforehand
3. Through careful analysis of and attention to when we arere gaining true understanding, one ought to be able to establish, at least tentatively, general principles all causal explanations must be based on
   a. These laws and general rules of nature will then constrain causal explanations of particular phenomena
   b. Thus vastly restricting the range of hypotheses that need to be considered in pursuing the more specialized causal processes governing particular phenomena
4. The range of hypotheses can be further constrained by insisting on single, comprehensive account of all phenomena
   a. Requiring the various causal explanations not just to be consistent with one another, but to complement one another in accounting for some phenomena

      "You say that there is nothing so easy as adapting some cause to an effect. But although there certainly are several effects to which it is easy to adapt diverse causes, one to each, yet it is not so easy to adapt one identical cause to several different effects, unless it is the true cause from which they originate. There are even often some which are such that to give a cause from which they can be clearly deduced is sufficient proof of their true cause." [letter to Morin, fn to 42]

   b. In effect, classic detective work in which attempting to infer the best total explanation of the full range of phenomena, including aspects which mislead

      "And we shall know that we have correctly determined these causes when we observe that we can explain [*explicare*], by their means, not only those phenomena which we have considered up to now, but also everything else about which we have not previously thought." [42]

5. Not a hypothetico-deductive logic of evidential reasoning, but one that is highly constrained and regulated versus the standard story of hypothesis formation, deduction, and comparison
   a. Hypotheses are put forward about unseen underlying structures and processes, under the requirement that the overall system of hypotheses be comprehensive and consistent
   b. Principles of geometry and fundamental laws of nature, through which these structure and processes effect their empirical consequences, then allow "explications" of phenomena as part of a larger picture – yielding explanations and understanding of the phenomena
   c. Comprehensive accord with the phenomena then reduces the probability of error, for comparatively few sets of hypotheses can yield a unified comprehensive account of all phenoomena

d. In Descartes' own case, grounding fundamental laws of nature in metaphysics further reduces risk of garden-path

6. Although the *Principia* pursues only qualitative agreement with phenomena, the Cartesian conception is more than just compatible with pursuing exact quantitative agreement, where this is known to be appropriate and not just building on air

a. The overall theory serves to tell us what is nomological, and hence it safeguards against our jumping to conclusions on the basis of merely apparent regularities

b. But where appropriate -- as in optics -- exact agreement will provide a high standard of evidence

C. Empirical Dimensions of Cartesian Science

1. That Descartes was indispensably turning to empirical evidence throughout Parts III and IV of the *Principia* is obvious

a. It is often said that the goal of Cartesian science is to reduce all material processes to geometry

b. But the vortex theory is not geometry; the evidence put forward for it is strictly empirical, whether in the form of an analogy with everyday fluid vortices or in the form of broadly "hypothetico-explanatory" reasoning to empirical theory

c. If there is some sense in which it is not empirical, or it is less empirical than say Galileo's theory of natural motion, then that sense is more subtle than is often recognized

2. On the view I am proposing, the main features of the approach taken in the *Principia* represent not a way of trying to avoid or minimize the appeal to empirical considerations, but a way of assuring that those considerations are marshaled most effectively

a. Descartes is taking on a classic problem in empirical science: to devise a theory of unseen causes from their effects

b. Admittedly, a lot of the worst science has arisen in the pursuit of such theories; Salviati's response to Sagredo's remarks about impetus in the "Third Day" is well taken

c. But to deny such theorizing a role in empirical science -- indeed, a central role in much of the most successful science -- is to turn one's back on such things as atomic theory

d. The question is, how to theorize about unseen causes safely

3. The principal empirical dimension of Cartesian science is the insistence on a single comprehensive causal account of all phenomena

a. This imposes exactly the same sort of empirical constraint on theorizing as is imposed in standard detective work: inference to the best total explanation

b. From this point of view, the correct line of response to e.g. the vortex theory is not to dismiss it as so much conjecture, but to show either that it is failing to explain various phenomena or that there is an alternative better total explanation

c. Either of these responses is clearly empirical, which shows that the vortex theory itself is inviting an empirical response

4. Descartes himself rejected the idea that the foundations of the theory -- the laws of nature etc. -- were empirical, but, as suggested above, the Cartesian concept of science was not viewed at the time as vitiated by allowing a further empirical dimension
    a. Empirical evidence for the foundations -- i.e. for the way of conceptualizing -- via the success in achieving a total explanation of the phenomena
    b. Empirical foundations open to empirical revision in response to recalcitrant phenomena or alternative total theories
    c. Allow the discussion of the adequacy of the total theory to extend to the foundations as well
5. The progressively stronger claims that Descartes makes for his account at the end of Part IV display such empirical dimensions
    a. Minimal defense: even if theory false, it will be as good as a true theory insofar as all its empirical consequences are true -- the best "as-if" theory [204]
    b. Stronger defense: morally certain -- i.e. certain to a degree that suffices for everyday life -- for "it could scarcely have occurred that so many things should be consistent with one another, if they were false." [205]
    c. Strongest defense: at least bordering on mathematical demonstrations, for virtually forecloses any alternative explanation

        "If they sufficiently understand that we can feel no external objects unless some local movement is excited by them in our nerves; and that such movement cannot be excited by the fixed stars, very distant from here, unless some movement also occurs in these and in the whole intermediate heaven: for once these things have been accepted, it will scarcely seem possible for all the rest, at least the more general things which I have written about the World and the Earth, to be understood otherwise than as I have explained them." [206]

D. The Two Senses of 'Theory' in Science

1. Descartes' insistence on having at least the broad outlines of a comprehensive explanatory scheme can also be viewed as a response to the pursuit of empirical evidence, and not just a commitment to philosophical goals (as Drake would have it)
    a. Interlocks diverse areas of research, so that evidence in one area can become evidence in others
    b. Potential for an enormous increase in the range of data that can be brought to bear
    c. Can help safeguard against being misled by phenomena taken in isolation, just as Descartes says in his critique of Galileo
2. Can thus view the basic explanatory scheme Descartes relies on, including the analogy with fluid vortices, as another type of working hypothesis adopted to facilitate empirical evidence
    a. Facilitates taking phenomena and surface data and turning them into evidence about details of underlying mechanisms
    b. Helps in deciding which such data can be trusted, and which should be treated cautiously as perhaps not nomological

3. Bromberger (in, for example, “Science and the Forms of Ignorance”) points out that there are two senses of 'theory' in physics, as contrasted by 'atomic theory' or 'the vortex theory', on the one hand, and 'the special theory of relativity', on the other
   a. $Theory_2$: question-answering devices, like Kepler’s orbital theory (and Ptolemy’s!)
   b. $Theory_1$: general account of underlying processes and mechanisms, like Descartes'
4. There are controversies about the importance of $theory_1$ in empirical science, and assuming it important, what the relation is between $theory_1$ and $theory_2$ in the process of developing evidence
   a. Perhaps $theory_1$ plays only a heuristic role, helping us to motivate and conceptualize research
   b. But then look at modern atomic theory, where such a limited view hard to maintain
5. Main point here is that one can at least argue that the broad outlines of an explanatory scheme can help in the development of evidence, especially in the early stages of theory construction
   a. Constant danger is being led into mistaken conclusions by limited data
   b. By tying different areas to one another, explanatory scheme can reduce this risk
6. Of course, in process must be careful not to let explanatory scheme become a dogma that is impeding rather than facilitating the development of evidence

E. Grounds for Objecting to Cartesian Science
1. What then is so wrong with the conception of science exhibited in Descartes' *Principia*
   a. Reluctant to say that the only thing wrong is that content is false, as we can now so clearly see
   b. Our sense is that something is wrong methodologically -- something that those living at the time ought to have been able to see -- that separates this book from science
2. The one gain we have made is that we have not been so dismissive of the Cartesian conception that we have to be similarly dismissive of all those who at the time found it compelling -- and of others who have found similar conceptions compelling since then
   a. Attention to conceptual foundations -- i.e. to basic why-questions -- legitimate, though undoubtedly want it to be more open to empirical shaping than Descartes did
   b. Goal of unified comprehensive explanatory theory legitimate if only because it will allow more diverse data to be brought to bear
   c. Adopting at least the outlines of an explanatory scheme at the outset reasonable, for need some sort of theory in order to begin marshaling data at all -- e.g. to assess the risk of drawing conclusions from various sorts of data
3. My suggestion for what is wrong with the "science" in the *Principia* is that these elements are not really exploited to the end of marshaling empirical evidence, but instead to the polemical end of excluding alternative approaches and theories
   a. The defense of these elements offered above is that they can enhance the process of turning empirical data into evidence -- e.g. in developing the detailed physics of our vortex system
   b. For example, suppose the rules governing change in motion, together with observations of fluid

vortices, had allowed empirically based inferences about the characteristics of the unseen ethereal fluid forming the vortices or the specific velocity variation versus the radius of a vortex

c. But this is not what the rules are used for; they are used to legitimate a further elaboration of hypotheses by providing a device for warding off potential objections -- this in contrast to allowing empirical factors to warrant further hypotheses

4. Much the same objection is to be lodged against Descartes' laws of motion
   a. The problem does not come just from their introducing a different notion of force -- '*vis*', '*vires*' -- from Newton (and Huygens)
   b. Their whole point should be to provide empirical access to the unseen forces they posit
   c. Whether the way of conceptualizing that they offer is worth adopting can then be evaluated by the quality of the empirical access they provide -- e.g. by converging evidence in support of particular measures of force, etc.
   d. But Descartes goes on to block using them to infer forces from phenomena of motion, because of the complexity of fluid-like motion in a universal plenum
5. I am the first to grant Descartes that elements of theory_1 are indispensable in the early stages of theory construction, and that high quality empirical evidence is hard to come by in the early stages
   a. But the consequent danger of forming a theory "entirely built in the air" -- as he accuses Galileo of -- demands that empirical considerations be brought to bear as early and often as possible as theory is being developed
   b. And this can be done in the early stages by demanding of the theory that it be successful in allowing empirical data to be turned into empirical evidence -- in demanding that any initial theoretical commitments pay off by permitting questions to be more amenable to empirical answer than without them
   c. If, for example, a way of conceptualizing is not leading to better empirical evidence, what grounds are there for retaining it at the time, instead of trying something else
6. By my stock, then, Descartes' mistake in concluding that he had overwhelming evidence for "the more general things which I have written about the World and the Earth" (IV, 206) lay in placing way too much weight on being able to explain various phenomena, and too little on whether he was in a better position to conduct ongoing empirical inquiry
   a. The ability to explain a finite range of phenomena is not very good evidence that no future phenomena will be encountered in conflict with the explanations
   b. But the ability to bring empirical considerations to bear more effectively, allowing the theory to be reshaped and refined empirically, is good evidence that you have gotten somewhere toward being able to answer questions about the world
   c. And it is also evidence that all will ultimately come out in the wash; even if the starting point is false, empirical evidence will ultimately allow the starting point to be corrected

F. Why Cartesian Science was so Well-Received

1. That still leaves the question why Cartesian science caught on so strongly in the second half of the 17th and first half of the 18th century, at least on the Continent
   a. In the face of the advances Kepler had made in astronomy and Galileo in the mathematics of motion, both of which were followed up by continuing advances during the period when Cartesian was so widely accepted
   b. Indeed, caught on so strongly that many found Newtonian science fundamentally inadequate when considered side-by-side with it
   c. Tentative answer here derives from recognizing that empirical research can have different aims which may rarely be readily reconcilable with one another
2. One aim: to provide an account of the world around us that gives us a better understanding of it, at least to a reasonable degree of detail -- that is, at least in broad outline
   a. General answers to why- and how-questions that are not *ad hoc*, but instead invoke a relatively small number of fundamental principles
   b. A unified way of conceptualizing and explaining the world around us, at least qualitatively
3. An alternative aim: to marshal empirical considerations toward establishing secure -- i.e. once and for all -- answers to those questions that (at the time) lend themselves to such answers
   a. Focus on those questions for which seemingly conclusive empirical answers can be obtained, *whatever those questions at any time happen to be*
   b. Getting beyond conjecture as an end in itself, as much as possibly imitating mathematics
4. Still another aim: to provide means for improving our daily practical lives, especially through enabling us to achieve ends we otherwise could not achieve
   a. For example, to be able to effect an end consistently that in the past we have been able to effect only occasionally
   b. Focus on those areas where human wants and needs are greatest, regardless of the quality of understanding or the strength of the evidence for underlying principles
5. Proposal: at the time Cartesian science emerged there were comparatively few examples of success in achieving either the second or third aims,
   a. Aristotle had provided an example of the first aim for centuries, and its collapse had created a demand for a comprehensive replacement
   b. Ptolemy, the classic example of the second aim, had been exposed as a failure, leaving questions about the extent to which any precise empirical claims could be established with finality
   c. Too many loose ends in e.g. Kepler and Galileo for them to serve as exemplars at the time for most people, who wanted first and foremost a big picture
6. Regardless, this course has a built-in bias toward the second aim, but not because I am insisting that it should have primacy over the other two

a. Merely because the question of the course -- how did we first come to have high quality evidence in any of the sciences? -- imposes that bias from the outset

b. And also because of the focus on Newton's *Principia*, which itself is presented not just as pursuing that aim , but as an exemplar for how to do it

7. An important consequence of this bias is my not even attempting to present an account of Descartes' vortex theory in the detailed form that made it so plausible to him

a. In other words, I have not even attempted to give the sort of account Kuhn calls for, in which the claims made by the science come to be viewed in the context of the contextual scheme and external circumstances that gave them the force they had at the time

b. The goal of this semester is to put us in a position to read Newton's *Principia* in this manner, but considerations of time have then forced me not to do so for Descartes in particular, and Kepler and Galileo to a lesser extent

c. A model of a Kuhnian account of Descartes' vortex theory can be found in Schuster (2005), worked out by focusing not on his *Principia*, but on the genesis of the theory leading up to the version of it in *Le Monde*

G. 1651: A Transition into "Modern" Science

1. The remainder of this course will take a seemingly abrupt turn toward science as we know it now, with many "textbook" elements of science emerging, one right after another

a. Not just in contrast to Descartes, but to Kepler and Galileo as well

b. The obvious question, granting its premise, is why, seemingly so suddenly, at this juncture of the seventeenth century

2. The basic answer is that a new post-Scholasticism generation emerges, with little felt need to build anew from the ground up, choosing instead to proceed from where their predecessors left off

a. Galileo dies in 1642, Torricelli in 1647, Mersenne in 1648, Descartes in 1650, Gassendi in 1655

b. The new generation, which came of age after Galileo's trial, was more post-Galilean than post-Copernican

c. In particular, the new generation had no need to fight the old battles all over again

d. Horrocks as an example of picking up from where Kepler left off and pushing forward

3. That alone, however, does not explain why a different sort of science seems to emerge so abruptly; to explain that we need to identify what it was in the heritage received from their predecessors that at least enabled, if not automatically engendered a different sort of science

a. The recognition of how different science became is surely retrospective, for other than Newton those at the time seem to have seen themselves as continuing along existing lines

b. In other words, they did not see that matters had changed as much as we can now see it

4. Let me propose, from very much a retrospective standpoint, that the following five elements having become part of the scientific culture, so to speak, were why science changed in mid-century