H. Descartes' Vortex Account of the Tides

1. A still further phenomenon for which Descartes invoked his vortex theory is the ebb and flow of the seas, but in Part IV rather than Part III
    a. Giving us a third astronomy-related account of the tides, in addition to those of Kepler and Galileo, though independent of the latter's insofar as it was already present in *Le Monde*
    b. The reason why this terrestrial phenomenon is being given astronomy-related accounts by all three is that the patterns of high tides correlate with the positions of the moon and sun
    c. Descartes' account is like those of Kepler and Galileo in making the moon's location crucial, but it differs not only from theirs otherwise, but also from Newton's subsequent account
2. The problem posed by the tides: high tide occurs twice a day (in most places), a little more than 12 hours apart, with a monthly cycle that correlates with the rotation of the moon around the earth
    a. High tide at any place is delayed typically an hour or so after the moon crosses the meridian
    b. Highest tides typically occur during full moon and new moon, though both the heights of the tides and patterns of variation differ from one place to another
    c. In addition to the latter variation, the height of the highest tides displays an annual variation
3. Descartes' account [IV, 49-56] invokes the effect of the presence of the moon on the motion of the vortex around the earth that carries it; in particular, the reduced space for the vortex to flow causes the fluid in it to move more swiftly at the line between the moon and the earth
    a. One effect of this is a displacement of the earth away from the moon along this line (resembling to some extent Galileo's thought that the moon and earth are moving in orbit around their common center of gravity)
    b. As a consequence, the space for the vortex to flow across the line from the moon to the earth extended to the other side of the earth is also reduced, with the result that the fluid moves more swiftly on the reverse side of the moon as well
    c. The swifter the fluid matter in the vortex, the more pressure it exerts on the surfaces of both the air and water, causing the water to recede on both sides of this line
    d. (Two problems: Daniel Bernoulli's law says that the pressure in a fluid varies inversely with its velocity; high tide occurs closer to the ends of the diameter of the earth that extends to the moon than the diameter 90 deg away from it)
4. Other features of the tides Descartes then presents as derivative from this basic mechanism:
    a. The time between high and low tide is a little greater than 6 hours because the moon moves forward in its orbit as the earth turns [IV, 50]
    b. Tides highest for full and new moon because vortex not perfectly round [IV, 51]
    c. Tides are higher at equinox because it is then that the plane of the earth's equator intersects the plane of the moon's orbit [IV, 52]
    d. Local variations from local variations in depths near shores [IV, 56]

5. Notice the feature common to three accounts: a celestial cause of a terrestrial phenomenon
    a. Not a wild sounding idea, if only because of the long-standing tradition of astrology
    b. Regardless, explaining the tides became a demand for astronomical theories

III. Ramifications of the Vortex Theory

A. A Candidate for the Underlying Physics

1. One thing that makes Descartes' vortex theory so important is that it offers a coherent, plausible alternative to the defunct crystalline sphere cosmology
    a. Descartes offers not just a new world picture, but a unified explanation of why that picture makes sense physically
    b. In this respect, the first real alternative to the old cosmology and late 16th century variants on it
2. Kepler's magnetic account of the physics underlying planetary motion could perhaps be considered an alternative too, but in the 1640's it had comparatively few adherents, for a combination of reasons:
    a. It was always regarded as ad hoc, with little independent evidence or rationale behind it
    b. People were unable to duplicate some of its required magnetic effects in experiments, such as a magnetically induced rotation appealed to in explaining the rotation of the earth, not to mention a magnetic flux around rotating bodies that puts other bodies into motion
    c. It was inconsistent with mechanical philosophy, hence saddled with an added burden of proof
    d. It was not in strict keeping with the principle of inertia that was coming into vogue -- in particular, it offered no account of what deflects bodies into curvilinear motion
3. Descartes' vortex theory, by contrast, was completely consistent with the mechanical philosophy, and it was responsive to the problem of centrifugal tendency
    a. Of course, it was ad hoc in many ways too, for it scarcely derived from Descartes' third law of motion or rules of impact, and it failed to address specifics of the orbits in the way Kepler had
    b. But much of it seemed dictated by the mechanical philosophy, lessening the ad hoc character, and other details were then inferred fairly directly from phenomena
    c. And it was built off a terrestrial phenomenon less mysterious than magnetism, namely fluid vortices, supported by the inference that something, even if unseen, acts on orbiting bodies
4. The picture of the universe it offers contrasts with both Kepler's and the older picture in ways that made it appear less simple-minded and more interesting
    a. E.g. no sphere of the stars, but separate star-centered systems all over the place, at indefinite distances
    b. A systematic, natural account of comets and of the origin of the planets
    c. With an account of light as an integral part of the story
5. One final contrast: a dynamic, doubtlessly evolving system, but subject to basic constraints from the fundamental principles of motion
    a. New comets, novas, deaths of stars, capture of satellites, etc.

b. Much more consistent with what was being learned than the old perfect static system was
c. But still compatible with the perfection and immutability of God

B. An Attempt to End the Issue of Copernicanism

1. In the same spirit as Kepler in the *Apologia* and *Astronomia Nova*, Descartes recognized the obligation of any account of the physics underlying the planetary system to resolve the issue of the chief world systems
   a. Descartes himself was a Copernican, as *Le Monde* makes clear
   b. But he was also a devout Catholic, and hence for political reasons, if no other, he was in need of a solution that the Church would not object to
2. He joins others in rejecting the Ptolemaic system simply because it does not accord with (telescopically) observed phase phenomena, especially Venus
   a. Note that he takes the trouble to distinguish, with empirical arguments, between bodies that give off their own light and those that give off only reflected light
   b. Thus a new basis for distinguishing planets from stars and grouping the sun with the stars
3. Descartes' argument against Tychonic system grants that it yields same relative position predictions, but claims that it must in fact attribute "more motion" to the earth [38, 39]
   a. Motion here means displacement relative to contiguous elements [II, 25]
   b. Diurnal motion of heavens entails relative motion at interface with earth, and because latter so much smaller, more proper to conclude that it moves
   c. Since other planets are carried around the sun by fluid motion, Tychonic would have to postulate some remarkable action by which the earth is separated from fluid motion, implying it is moving even more with respect to the fluid surrounding it
4. Descartes' argument for the Copernican initially holds that it is simpler and clearer, but he subsequently supports this claim with the simplicity of the vortex (and vortex within vortex) picture [Figures IV and V]
   a. This picture is simple compared to how vortices must work in the Tychonic system, where have primary vortex around earth and secondary around sun, extending past Earth
   b. Not to mention the fact that the inner planets move in the opposite direction from the outer!
   c. An anti-Tychonic line more forceful than the one Descartes chooses to present
5. Descartes' solution for the Church: earth does not really move at all, in the strict sense, for no relative displacement between it and the fluid contiguous to it either in rotation or revolution, and hence no violation of Scripture [95]
   a. Motion e.g. from the point of view of observers outside the solar system
   b. But this is compatible with the Scriptures, for only the strict sense of motion is relevant to them
   c. {Scholars disagree about whether Descartes himself took this solution seriously or thought of it as a mere subterfuge}

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