c. 1655: first extended visit to Paris, where Gassendi introduces him to others

d. 1656: using his superior telescopes, discovers Titan (satellite of Saturn) and solves the riddle of Saturn's rings

e. 1656: designs first successful pendulum clocks, culminating in publication of his *Horologium* describing the design -- most notably, the escapement -- in 1658

f. 1657: first textbook on probability theory, inspired by his time in Paris and published as an appendix to a Van Schooten book -- Bayesian in spirit, emphasizing "expectation"

g. 1659: publication of *Systema Saturna*

3. 1660-1673: becomes the leading figure in the world of science

a. Late 1659: centifugal force, conical pendulum, cycloidal pendulum, measurements of g, cycloidal pendulum clocks

b. 1660 (and 1663-64) visits to London where he announces his results on impact, cycloidal pendulum, cycloidal pendulum clocks, and measurements of g

c. 1663: first foreign Fellow of the Royal Society

d. 1664: approached (by Colbert) to be a founding member of the French Royal Academy of Sciences, which he joins at its inception in 1666

e. 1669: cause of gravity, analytical and experimental efforts on motion under resistance, and trials of his clocks at sea (for finding longitudes); publication of his results on impact, announcing conservation of linear momentum, *vis viva*, and center of gravity principle

e. 1673: publication of his *Horologium Oscillatorium*

D. Huygens and the Measurement of g (1659)

1. During the last three months of 1659 Huygens became preoccupied with the problem of measuring the strength of gravity (as described in Joella Yoder's *Unrolling Time*)

a. He knew Riccioli's measurement, and he repeated Mersenne's, concluding that it could not be perfected to the extent needed

b. Initially addressed the problem Mersenne had posed -- compare the time for a pendulum to fall through 90 deg to the time of vertical fall through the same height

c. Knew, both from Mersenne and from his development of the basic pendulum clock, that the circular pendulum is not isochronous

2. First effort in an earlier version of De Vi Centrifuga, exploiting the discovery that uniform circular motion involves uniform acceleration just as vertical fall does

a. Leads to theory of conical pendulum, including result that the period of revolution = $2*\pi*\sqrt{(h/g)}$, as presented in our version of De Vi Centrifuga (published posthumously in 1703)

b. Infer g from measurement of period: 15 and 6/10 Rhenish ft "proxime" in the 1st sec (979 cm/sec/sec), by far the best value to date (Riccioli: 935 cm/sec/sec)

c. (Had he carried through his own calculation to more significant figures, would have obtained 15.625 Rh ft, or 980.9 cm/sec/sec)

d. Measurement by designing and building a conical pendulum clock (see Appendix)

3. Undoubtedly looking for a cross-check, turned to the infinitesimal arc pendulum, successfully deriving the comparable relation for it: $P = 2*\pi*\sqrt{(\ell/g)}$ -- versus Galileo's law, which said only that the periods were proportional to $\sqrt{\ell}$

   a. In the process, discovered a geometric relationship that has to hold to maintain isochronism over non-infinitesimal arcs

   b. From this determined cycloid is isochronous trajectory-- i.e. path of a point on a rolling circle

   c. And settled on a still better value of g: 15 Rh ft 7.5 in (i.e. 15.625 ft) fall in 1st sec (980.9 cm/sec/sec)

4. In conjunction with this, designed and built a cycloidal pendulum clock, and developed theory of evolutes along the way; clock from *Horologium Oscillatorium* shown in figure in appendix

5. One lesson learned in all of this is that theory itself can be an indispensable element in achieving accurate measurements and hence in getting the empirical world to answer questions

   a. Infer g from a comparatively simple measurement, combined with a theoretically derived relation, with cross-checking via a sequence of measurements for different arcs, ℓs, etc., and by measurements employing other theory-based devices

   b. Evidence accrues to theory through stability among repeated precise values and convergence of values from complementary theory-mediated measurements of the constant of proportionality

   c. Lack of agreement instructive -- e.g. defect in experimental design, or flaw in theory

6. Huygens's precise measurement repeated by many, usually using a seconds-pendulum -- i.e. a simple, small-arc pendulum of length 3 Paris ft 8.5 lines -- giving a value for fall in first second of 15 Paris ft 1 in (980.7 cm/sec/ sec, versus current value of 980.97 in Paris)

   a. Much stronger evidence for uniform acceleration in vertical fall than anything preceding, for now a stable, convergent, precise value for rate of acceleration (in mid-latitudes of Europe)

   b. A powerful method of evidence for theory that has been central to physics ever since: obtain stable, convergent, ever more precise values of fundamental parameters of theory through theory-mediated measurements

   c. Huygens himself seems not to have taken much notice of this method of evidence, but, as we shall see, Newton took great notice of it

7. Measurement so reliable that Richer able to infer a 0.35% variation in g between Paris and Cayenne from a 1 and 1/4 line difference (2.8 mm) in the length of seconds-pendulum (see Appendix)

   a. I.e. able to extract evidence from discrepancies between one measurement and another

   b. Will see the importance of having such a precise measure of g in subsequent developments