zation of how much less was known and understood than had been thought, driving home how much more ignorant we are than the learned at the time thought we were

3. First major discovery was the complexity of the surface of the moon -- in direct contrast to celestial perfection, as per Aristotelians
    a. Mountain ranges and craters, as drawn with a reasonable amount of skill
    b. Shadows in relationship to the sun used to infer that the indications seen were mountains and craters, including accurate mountain heights (roughly 4 miles) and "earth-shine"
    c. Opened the way to "exploration" of the moon and lunar selenography
4. Second major discovery was the huge number of additional stars revealed for the first time by the telescope, including fact that the Milky Way is made up of numerous stars
    a. Number of additional stars underscores the parochialism of human vision and the inappropriate emphasis laid in the past on what we happen to be able to see
    b. Also, small size of stars under magnification, versus size of planetary disks, gives new grounds for distrust of appearances and for accepting vast distance to stars, as required by the Copernican system
    c. Undercuts age-old dogmatism: we thought we knew so much about the celestial sphere, but now found we have just begun
5. Third major discovery was the four "planets" revolving around Jupiter: Io, Europa, Ganymede, and Callisto (Mayr's names)
    a. Galileo did not wait to determine periods or orbits of the four, though he did make clear that the periods were much shorter than those of our moon
    b. Strengthens plausibility of Copernicanism by removing oddity of our moon and showing rotation about bodies other than the earth
    c. Again undercuts age-old dogmatism: planetary astronomy has new work to do
6. Besides undercutting dogmatism (especially the dogmatic tendency to consider so many major questions long settled by Scholastic natural philosophy), *Sidereus Nuncius* opens the possibility of a whole new domain in which to pursue evidence in astronomy
    a. Another way of turning questions in astronomy into empirical questions -- expand the range of empirical observations
    b. Not just old questions, like which system, but also a whole new set of empirical questions, such as ones concerning the orbits of the "satellites" of Jupiter
    c. Not surprisingly, Kepler's reaction in his "Conversation with the Sidereal Messenger" (May, 1610) emphasized such things
7. Finally, note the paragraph announcing his book on the System of the World (p. 45) -- first use of 'system' in this regard?

B. Galileo's Telescopes: Design and Limitations

1. Galileo describes three telescopes, one of roughly magnification 3, another of nearly 8, and another (he says) of 30, for which he ground the lenses himself

a. Others (e.g. King) report him as developing four telescopes, the third of magnification 20 used for the moon and a fourth of mag 30 (with stepped down aperture) used for Jupiter

b. The pair recently evaluated have magnifications of 14 and 21 (see Appendix)

c. Galileo was thoroughly familiar with theoretical optics at the time, but this was not much of a guide, for Snel's law of refraction was not published until 1637 (Descartes)

2. The design was of the type known now as a "Dutch telescope", using spherical convex and concave lenses in a tube around 1 meter long and 2 to 4 cm in diameter

   a. Galileo's planar-convex and planar-concave (not as good as bi-spherical convex and bi-spherical concave)

   b. Idea: concave lens brings rays converging to focus, and interposed convex diverges them, yielding erect image of magnification f1/f2 (King, p. 36, Thompson, p. 3)

3. Original instruments were surely crude, Galileo's great skills as a craftsman notwithstanding

   a. From his comments and those of others, clearly a lot of irregularities in the ground spherical surfaces of many telescopes at the time

   b. Apparently not much attention to mounting -- either hand-held or on simple tripod or cradle -- which would have made the image a little shaky at best

4. Worse, unbeknownst to Galileo, lenses of this sort subject to serious optical distortions

   a. Spherical aberration: rays do not come to a definite single focus with a spherical lens; rays incident on edges focus nearer the lens than rays incident near center, resulting in fuzzy images, especially when looking at small objects

   b. Chromatic aberration: rays of different colors spread, focusing at different lengths, resulting in multi-colored, hazy edges

   c. Net effect is a telescope far removed from current day amateur scopes, a telescope requiring notable skill in "seeing"

      "When the object is both white and brilliant, like the planet Venus near maximum elongation, the image cannot be focused sharply and is marred by an encircling halo of intense hue." (King, p.43)

5. Galileo did find tricks, like stepping down the aperture (to 1.5 to 2.5 cm), to improve the image

   a. But this results in a reduced field of view -- e.g. 15 min of arc, 1/2 the diameter of the Moon

   b. And light gathering down to not much more than human eye, resulting in faint images

   c. Galileo reached pretty much the technical limits of the Dutch telescope almost from the beginning -- e.g. a useful magnification of not much more than 20

6. Recent laser assessments of Galileo's lenses have revealed that his personal lenses were much better than has long been thought – a testament to his skill as a craftsman (see Appendix)

   "Although affected by intrinsic chromatic aberration, at single wave length the telescopes are nearly diffraction-limited, that is, optically perfect." (Greco, Molesini, Quercioli)

(For more details on the telescopes and to gain access to all of Galileo's writings, published and otherwise, along with digital cross-references to related works, (many with translations into

English) turn to the website of the Institute and Museum of the History of Science in Florence (IMSS, Florence), www.imss.fi.it)

7. In a sense telescope extended the range of the observable and hence the range of observable phenomena (e.g. Jupiter's moons), but it did so in some respects problematically
    a. Need for "interpretation" in order to decide which aspects of what was being seen were veridical, and which were not -- e.g. chromatic aberration
    b. Some of Galileo's opponents dismissed telescopic observations as some sort of illusion -- natural observation the realm of phenomena
    c. Kepler's *Dioptrice* (and later Descartes' *Dioptrique*) respond to this worry by providing a theory that shows the analogy with the human eye and allows the veridical to be distinguished from the non-veridical

C. Further Telescopic Discoveries: 1610-1620

1. Galileo made a number of further discoveries in the months, and then years, following the *Sidereal Messenger*, and others of course made ones in parallel (and competition) with him
    a. Harriot and his friends in London, a group in Aix en Provence led by Fabri de Peiresc, Fabricius in northern Germany, Scheiner in Ingolstadt etc.
    b. (And also Father Clavius at the Collegio Romano, the leading authority on Ptolemy, who certified Galileo's observations, though not his interpretations)
2. Major new discovery: sunspots, revealing that the sun is not the perfect body Scholastic philosophers said it was
    a. Shows that sun rotates (confirming Kepler's hypothesis), for multiple spots move uniformly in tandem (around 25 day period)
    b. Published "Letters on Sunspots" reporting these discoveries plus the next two below, with increasingly open Copernicanism
    c. Claims disputed by Scheiner, leading to exchanges
3. Major new discovery: Venus displays a full cycle of phases, including a "full Venus", which is extraordinarily difficult to explain except by conceding that Venus orbits the sun (see figure in Appendix)
    a. The most devastating blow to Ptolemaic theory, though trivially okay on Tychonic
    b. Galileo tried and failed to observe phases of Mercury -- a comment on the quality of his telescopes and the difficulties of observing Mercury; still claimed to have seen them
4. A further discovery: Saturn has two “small stars” on either side, seemingly tied to it that neither Galileo nor others can figure out (until Huygens in the 1650's, with far better telescopes)
5. A determination of the periods of the four Galilean satellites to within 0.05% (correct mean Synodic values are 1.769, 3.551, 7.155, and 16.689 days with eccentricities 0.000, 0.000, 0.002, and 0.008)
    a. Gets the idea of using eclipses of these satellites as a means of determining differences in local time and hence longitude on earth, but then discovers that synodic periods not quite