

Figure 2. [In colour online.] *Kepler's New Astronomy* by Nicholas Wade. The title page of Kepler's (1609) *Astronomia Nova* is shown together with a portrait of Johannes Kepler (1571–1630), based upon an engraving (by Jakob von Heyden), and he is placed in the inverted and reversed letters of the words RETINAL IMAGE.

as the receptive surface, rather than the crystalline lens as had previously been thought. However, the optical image on the retina was inverted and reversed, and this did not correspond with perceptual experience. It was thought that the retinal image was a picture, and that this representation required reversing and inverting in some way. Kepler was reluctant to entertain speculations as to how this might come about, considering it beyond the realm of physics: “I say that vision occurs when an image of the whole hemisphere of the world that is before the eye, and a little more, is set up at the white wall, tinged with red, of the concave surface of the retina” (Kepler 1604, translated in Donahue 2000, page 180).

Galileo and Kepler corresponded with one another but there is another, unexpected, bond between them and it involved Dundee! John Wedderburn (1583–1651), who was born in Dundee, studied mathematics with Galileo in Padua and then moved to Moravia, where he became chief doctor and where he died. In 1610, under the name Joannus Wodderbornius, Scotobritannus, he offered his (and Galileo's) answer to an attack on *Sidereus Nuncius* by one of Kepler's students (see Spini 1996; Wedderburn 1898). Kepler himself, while strongly disavowing the student's views, would soon write an important defense of Galileo in his *Dissertatio cum Nuncio Sidereo* (Kepler 1610). Galileo's *Sidereus Nuncius* was published on 12th March 1610, and on the very next day the English Ambassador in Venice, Sir Henry Wotton, sent a copy to King James I.

The accompanying note conveying a synopsis of Galileo's discoveries ended with the statement: "the author runneth a fortune to be either exceeding famous or exceeding ridiculous" (Smith 1907, pages 486–487).

Galileo's application of his vision was of fundamental importance for his astronomical revolution and for the new science that it introduced. In contrast to Kepler, he did not concern himself with the optics or the mechanisms of the eye, but directed his attention to phenomenology and philosophy of vision. Galileo not only made observations but examined observation itself, and the inferences that could be drawn from them (see Piccolino and Wade 2008). He utilised phenomena of visual contrast to support many of his astronomical arguments in both real and thought experiments. His general interest in the senses reflected their fallacies and limits and the ways in which scientific knowledge of the world could be gathered from potentially deceptive sensory appearances. For one who used his eyes with such telescopic skill it seems strange that Galileo did not examine their operation in more detail. He can be seen as part of an observational tradition in matters visual, in contrast to that based on optics. The paradox is that Galileo stood at the threshold of a revolution in visual optics, but he did not step over it. This was so despite the fact that he was closely associated with those who transformed the view of vision during his lifetime, particularly Kepler and Christoph Scheiner (figure 3). However, with his philosophical reflections on the senses, expounded especially in *Il Saggiatore*, Galileo (1623) laid down the founding principles of modern

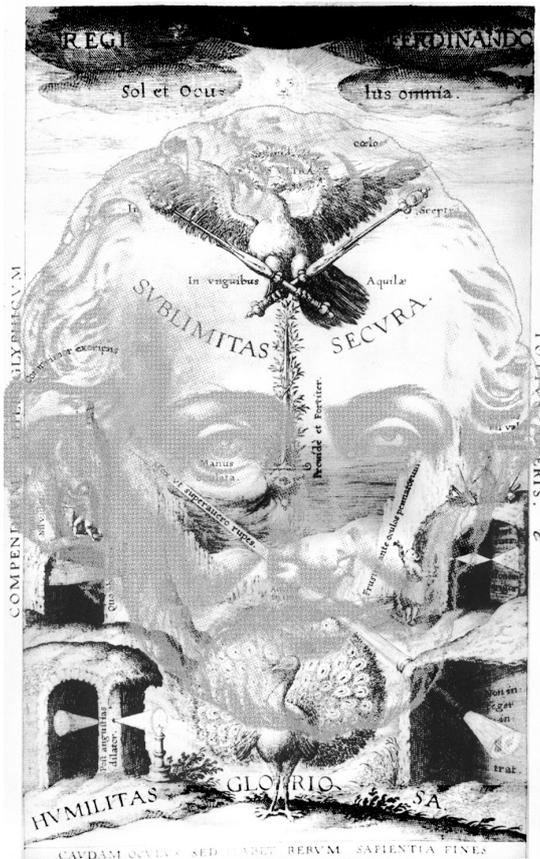


Figure 3. Scheiner's *Oculus* by Nicholas Wade. The portrait of Christoph Scheiner (1571–1650) is derived from a nineteenth century bust and it is embedded in the frontispiece of Scheiner's (1619) book on the eye, which illustrates many optical instruments and phenomena.

sensory physiology. The new philosophical doctrine of senses elaborated by Galileo was received with great enthusiasm in England by the cultural circle of William Cavendish, Duke of Newcastle; he had some of Galileo's works translated into English (although they have remained only in manuscript form).

Scheiner was also an astronomer and like Kepler concerned himself with visual optics. He provided the first accurate representation of the gross anatomy of the eye, based on dissections of the eyes of many animals: the lens and its curvatures were appropriately represented and the optic nerve left the eye nasally (Scheiner 1619). Scheiner appreciated that an equation of artificial and natural image formation could be made and he described how an artificial eye could be constructed. Some years later, he presented a pictorial analysis of optical image formation in the camera and the eye—with both inverted and upright images due to the addition of convex and concave lenses (Scheiner 1630). He noted that an upright retinal image resulted in inverted vision. Furthermore, Scheiner described how an image could be seen on the exposed surface of an excised animal's eye—an experiment he “had often performed”. The demonstration of an inverted and reversed image cast on the retina of an animal's eye, together with those from artificial eyes hastened optical analyses of vision.

Until the time of Galileo, Kepler, and Scheiner light and sight were not distinguished from one another because the dioptrics and the anatomy of the eye had not been adequately described. Two traditions operated in the period from Aristotle to that time, one of the analysis of vision in terms of optics and the other in terms of observation. Galileo can be regarded as continuing in the observational tradition which was further emphasised by his student and colleague, Benedetto Castelli (1578–1643). The optical tradition was to break new ground during Galileo's lifetime, due in no small part to his fellow astronomers, Kepler and Scheiner. They are all stars of seeing.

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Nicholas J Wade

University of Dundee, Dundee DD1 4HN, Scotland, UK; e-mail: n.j.wade@dundee.ac.uk

Marco Piccolino

Università di Ferrara, I 44100 Ferrara, Italy

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