letters

Lemaître's Hubble relationship

The detection of the expansion of the universe is one of the 20th century's most important scientific discoveries. It is still widely held that in 1929 Edwin Hubble discovered the expanding universe[1] and that his discovery was based on his extended observations of redshifts in spiral nebulae. Both statements are incorrect. The circumstances of the discovery were well documented in two books: *The Day We Found the Universe*, by Marcia Bartusiak, and *Discovering the Expanding Universe*, by one of us (Nussbaumer) and Lydia Bieri. Both books were positively reviewed in the December 2009 issue of PHYSICS TODAY (page 51). Other writers have stated the facts correctly as well.[2]

Alexander Friedmann in 1922 was the first to publish nonstatic solutions[3] to Albert Einstein's field equations. However, he did not extend that work into a cosmological model built on astronomical observations. Some five years later, Georges Lemaître also discovered dynamical solutions.[4] In the same publication in which he reported his discovery, he extracted (on theoretical grounds) the linear relationship between velocity v and distance r: $v = Hr$. Combining redshifts published by Gustaf Strömberg (who relied mostly on Vesto Slipher's work) and Hubble's determination of distances from magnitudes, he calculated two values for the Hubble constant H, 575 and 670 km s^{-1} Mpc^{-1}, depending on how the data are grouped. Lemaître concluded from those results that the universe was expanding. Two years later Hubble found the same velocity–distance relationship on observational grounds[1] from practically the same observations that Lemaître had used. However, Hubble did not credit anyone for the redshifts, most of which again came from Slipher.

Several of today's professional astronomers and popular authors believe that the entirety of Lemaître's 1927 French-language paper was republished in English[5] in 1931 with the help of Arthur Eddington. That is also incorrect; the two pages from the 1927 paper that contain Lemaître's estimates of the Hubble constant are not in the 1931 paper, for reasons that have never been properly explained.

Unfortunately, several prominent people writing in the popular press continue to promote Hubble's discovery of the expansion of the universe. See, for example, Brian Greene's Op-Ed piece in the *New York Times* on 15 January 2011.

There is a great irony in these falsehoods still being promoted today. Hubble himself never came out in favor of an expanding universe; on the contrary, he doubted it to the end of his days. It was Lemaître who was the first to combine theoretical and observational arguments to show that we live in an expanding universe.

References

1. E. Hubble, *Proc. Natl. Acad. Sci. USA* **15**, 168 (1929).
2. See, for example, P. J. E. Peebles, in *The Big Bang and Georges Lemaître: Proceedings of a Symposium in honour of G. Lemaitre . . .*, D. Reidel, Dordrecht, the Netherlands (1984), p. 23.
3. A. Friedmann, *Z. Phys.* **10**, 377 (1922).
4. G. Lemaître, *Ann. Soc. Sci. Brux.* **47**, 49 (1927).
5. G. Lemaître, *Mon. Not. R. Astron. Soc.* **91**, 483 (1931).

Michael Way
(michael.j.way@nasa.gov)
NASA Goddard Institute for Space Studies
New York City
Harry Nussbaumer
(nussbaumer@astro.phys.ethz.ch)
ETH Zürich
Zürich, Switzerland

Coriolis effect, two centuries before Coriolis

The Coriolis deflection of moving objects seen from within a rotating frame of reference—important in physics, meteorology, and oceanography—was described by Italian scientists Giovanni Battista Riccioli (1598–1671) and his assistant Francesco Maria Grimaldi (1618–63) nearly two centuries before Gaspard-Gustave Coriolis (1792–1843).

Among other things, historians attribute to Riccioli our system of lunar nomenclature and the first accurate measurement of gravitational acceleration at Earth's surface, and to Grimaldi the discovery and naming of the phenomenon of diffraction of light. Riccioli and Grimaldi give a detailed description in Riccioli's 1651 *Almagestum Novum* of how Earth's rotation should cause a rightward deflection in a projectile fired toward the north. They write,

> If a ball is fired along a Meridian toward the pole (rather than toward the East or West), diurnal motion will cause the ball to be carried off [that is, the trajectory of the ball will be deflected], all things being equal: for on parallels of latitude nearer the poles, the ground moves more slowly, whereas on parallels nearer the equator, the ground moves more rapidly.[1]

Grimaldi and Riccioli provide a diagram (see figure, next page) of a cannon aimed northward and eastward. They write that if the cannon is fired eastward at a target at B, then as the ball is in flight, Earth's diurnal rotation carries the mouth of the cannon from A to C and carries the target from B to D, so the ball travels from A to D. If the cannon is aimed northward and fired at a target at E, then as the ball is in flight, the target moves from E to N. However, the ball travels along the curve AKF, not the straight line AHF, because the diurnal motion is faster at the beginning of the ball's flight (page 426).[1]

The authors write that the ball will not strike the target at N squarely but will graze it or miss it. However, if another target were positioned east of N, such as at G, the ball would squarely strike it, even though the cannon is not aimed at it (page 427).[1]

Riccioli and Grimaldi do not calculate the size of the effect, but they suppose that since a skilled artilleryman can place a shot right into the mouth of an enemy's cannon, the difference in shots from east to west versus those

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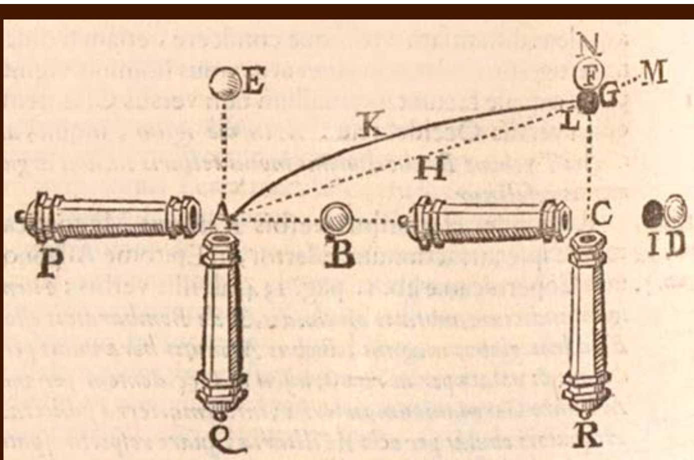

Illustration from Giovanni Battista Riccioli's 1651 *Almagestum Novum*. Because of Earth's rotation, a projectile fired north to hit a target at E/N follows curved path AKF, and strikes east of N at G. This effect is today referred to as the Coriolis effect, after the early 19th-century physicist.

north to south should have been detected. That it had not been they interpreted as evidence that Earth is immobile (page 427).[1] Riccioli and Grimaldi were geocentrists who supported the Tychonic theory—in which the Sun, Moon, and stars circled Earth while the planets circled the Sun—rather than the Copernican theory.

Christina Graney and I discovered this historic work accidentally, while researching how early astronomers interpreted telescope measurements of star diameters (which they did not understand to be spurious).[2] Riccioli discusses such measurements,[3] and thus we have been translating portions of his book.

Coriolis discussed motion in a rotating frame of reference in 1835. Siméon-Denis Poisson dealt with the deflection of projectiles in 1838. Earlier, in 1735, George Hadley noted the possible effect of Earth's diurnal rotation on winds.[4] Historian of science Edward Grant discussed Riccioli and Grimaldi's use of cannon balls fired in different directions to argue against Earth's motion, but did not mention that it describes the Coriolis effect.[5]

References

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2. C. M. Graney, T. P. Grayson, http://arxiv.org/abs/1003.4918v2.
3. C. M. Graney, *J. Hist. Astron.* **41**, 453 (2010).
4. For a discussion of the work of Hadley, Coriolis, and Poisson, see A. O. Persson, *Hist. Meteorol.* **2**, 1 (2005) and references therein.
5. E. Grant, *Trans. Am. Philos. Soc., New Ser.* **74**, 1 (1984); see p. 48.

Christopher M. Graney
(christopher.graney@kctcs.edu)
Jefferson Community and Technical College
Louisville, Kentucky

Student lab safety emphasized

The 14 April 2011 issue of my local newspaper contained a short note about a physics major at Yale University who was killed when her long hair became entangled in the machine lathe she was using. That was a tragic accident, but completely preventable. Industry tends to be careful about safety issues, partly because of liability problems and partly because a higher accident rate increases the cost of workers' compensation insurance. In my experience, academic institutions tend to be more casual about safety, and there seems to be the assumption that each researcher will deal with safety issues in his or her lab.

The accident at Yale reminded me of something that happened sometime between 1961 and 1966, when I was head of the physics department at Montana State University in Bozeman. The *Physics Teacher* published a picture of a young woman with long hair operating a drill press. That picture produced a strong reaction in me, and I had two pictures posed with one of our physics majors. One showed her leaning over the lathe with her long hair dragging on the chuck, and the other showed her in the same position with her hair in a kerchief. The *Physics Teacher* published both pictures, one labeled "This" and the other "Not This." Unfortunately, such basic safety measures get forgotten.

I urge PHYSICS TODAY and its readers to give attention to matters of laboratory safety. We should never have another accident like the one at Yale.

Irving E. Dayton
(daytoni@peak.org)
Corvallis, Oregon