Passage IV

NATURAL SCIENCE: This passage is adapted from the article "Warp Factor" by Charles Liu (©2003 by Natural History Magazine, Inc.).

Astronomers sometimes describe the shape of our home galaxy, the Milky Way, as a thin-crust pizza with a plum stuck in the middle. The plum is the slightly oblong central bulge, protruding about 3,000 light-years above and below the galactic plane, comprised mostly of older stars; it makes up the core of the Milky Way, and includes a black hole two and a half million times the mass of the Sun. The crust of the pizza is the galactic disk—the source of most of our galaxy's light. Thin and flat, the disk is 100,000 light-years across, about 1,000 light-years thick, on average, and includes more than 80 percent of the galaxy's hundred billion or so stars.

The plum-and-pizza picture works well enough, but like most simple metaphors, it breaks down if you push it. For one thing, the galactic disk isn't a rigid body, but a loose agglomeration of matter streaming around a common center of gravity. (The swirling pattern of a hurricane far better resembles our spinning galaxy.) For another thing, our galaxy's disk isn't flat; it's warped. Picture a disk of pizza dough spun into the air by a skilled chef: our galaxy goes through the same kind of floppy, wobbly gyrations, though at a rate best measured in revolutions per hundreds of millions of years.

Why does the Milky Way have such an odd-looking warp? No definitive answer has emerged. One thing we do know: when it comes to warps, our galaxy is hardly unique. About half of all spiral galaxies are warped to some degree. Theoretical and computational models have shown that a number of physical processes can warp a galaxy, so it's a matter of figuring out which scenario applies. An innovative analysis of the problem by Jeremy Bailin, an astronomy graduate student at the University of Arizona in Tucson, has implicated a small satellite galaxy, currently being ripped to shreds by the gravity of the Milky Way.

The Sagittarius Dwarf Spheroidal Galaxy was discovered in 1994. It appears to be in a roughly polar orbit around the Milky Way—that is, above and below the galactic disk—about 50,000 light-years from the galactic center. That orbit brings the dwarf galaxy far too close to the huge gravitational tidal forces of the Milky Way for the dwarf to remain intact. As a result, the Sagittarius Dwarf now looks something like strands of spaghetti spilling from the front of a pasta-making machine, the galaxy's matter being drawn out over hundreds of millions of years by intergalactic tides.

Gravitational collisions between small satellite galaxies and big spiral galaxies have long been regarded as possible culprits in the warping of a larger galaxy's disk. The best known satellite galaxies orbiting the Milky Way—the Large and Small Magellanic Clouds—are too far away, and have the wrong orbital characteristics, to have warped our galactic home. The Sagittarius Dwarf seems a much more likely candidate, simply because it is only a third as far from the center of the Milky Way as the Magellanic Clouds. But in astronomy—unlike in real estate—location isn't everything; to show a direct connection between warp and dwarf, the orbital motion of the Sagittarius Dwarf must be linked to the rotation of the Milky Way's disk.

Bailin's study is the first to find such a link. His analysis of the galactic warp is based on angular momentum—a measure of how much a system is spinning or rotating. Just as objects moving in a straight line have momentum, objects spinning or orbiting around an axis have angular momentum; and just as the momenta of two objects combine when they collide, so too do their angular momenta. Imagine two figure skaters coming together for a combination spin. When they make physical contact, their individual spiraling motions combine to produce a single, unified whirl.

Starting with the latest measurements of the structure and spin of the Milky Way, Bailin deduced the angular momentum of the warped portion of the Milky Way's disk. He then compared that measure with the angular momentum of the Sagittarius Dwarf—and found for the first time, within the margins of measurement error, that the two angular momenta are identical in both quantity and direction. Such a coupling of the angular momenta of two bodies almost never happens by chance; usually, it takes place only when two spinning systems, like the skaters, come into contact. The coupling isn't enough to prove cause and effect by itself, but it's solid circumstantial evidence that the interaction of the Sagittarius Dwarf with the Milky Way disk created the warp in our galaxy.

31. Which of the following statements best expresses the main idea of the passage?

- **A.** Bailin began studying the Sagittarius Dwarf when he was a graduate student in astronomy.
- **B.** The gravitational tidal forces of the Milky Way are destroying the Sagittarius Dwarf.
- **C.** Most astronomers have come to an agreement that evidence about how galaxies have formed is, at best, circumstantial.
- **D.** Evidence suggests that the warp in the Milky Way's disk results from the Milky Way's interaction with a small satellite galaxy.

32. It can reasonably be inferred that the problem the author mentions in line 33 refers to:

- **F.** a particular aspect of Bailin's theory for which there is little evidence.
- **G.** a mathematical computation that led Bailin to focus on the Sagittarius Dwarf.
- **H.** the question of which physical processes caused the warp in the Milky Way.
- **J.** the potential impact of wobbly gyrations on the Milky Way's rotation.

33. It can reasonably be inferred from the passage that the small satellite galaxy referred to in lines 35–36 is:

A. the Small Magellanic Cloud.
B. the Sagittarius Dwarf.
C. a known but as yet unnamed galaxy.
D. a hypothetical galaxy that is believed to exist but has not yet been found.

34. Based on the passage, which of the following statements best describes Bailin's study as it relates to the field of astronomy?

F. It led astronomers to the discovery of a warp in the Milky Way's disk.
G. It convinced more astronomers to focus their attention on the center of the Milky Way.
H. It revealed problems with the basic assumptions held by most astronomers.
J. It provided evidence for an idea that scientists had long considered a possibility but had not yet proved.

35. According to the passage, Bailin discovered that the angular momentum of the warped portion of the Milky Way and the angular momentum of the Sagittarius Dwarf are:

A. identical in quantity but different in direction.
B. identical in direction but different in quantity.
C. identical in both quantity and direction.
D. different in both quantity and direction.

36. According to the passage, the central bulge of the Milky Way is comprised of:

F. 80 percent of the galaxy's stars.
G. older stars and a black hole.
H. a galactic plane and several dwarf planets.
J. a loose agglomeration of unidentified matter.

37. The author refers to the swirling pattern of a hurricane primarily in order to:

A. help explain the shortcomings of the plum-and-pizza metaphor.
B. argue that the unpredictability of the rotation of spiral galaxies requires a new metaphor.
C. emphasize the particular aspects of the Milky Way that make it unique.
D. describe how the movement of the Milky Way creates gravitational tides.

38. The passage directly compares the Milky Way's disk as it is affected by its warp to:

F. a pasta maker churning out spaghetti.
G. pizza dough being spun in the air by a chef.
H. a thin-crust pizza balanced on top of a plum.
J. two figure skaters coming together for a combination spin.

39. According to the passage, which of the following statements best describes the movement of the Sagittarius Dwarf with respect to the Milky Way?

A. It appears to be in a roughly polar orbit around the Milky Way.
B. It appears to orbit the Milky Way at an angle of roughly forty-five degrees.
C. It follows the movement of the stars in the Milky Way's disk, though at a slightly faster rate.
D. It once followed the movement of the stars in the Milky Way's disk, but now seems to move erratically along its own path.

40. The passage describes angular momentum as the amount of a system's:

F. vertical deviation within an orbital path.
G. movement in a straight line through space.
H. gravitational pull.
J. spin or rotation.