the hypophyseal portal system (*28*). Thus it may be that brain areas mediating pain inhibition are reached via this route by opioids of pituitary origin in concentrations sufficient to cause analgesia. The intriguing possibility also exists that the ventricular system normally serves as a conduit for transporting pituitary opioids from ventrobasal regions of the hypothalamus to the more distant periventricular and periaqueductal structures thought to be involved in endogenous mechanisms of analgesia.

It is also possible that naloxone-sensitive stress analgesia is mediated in part by opioid release directly within the brain. In fact, it has recently been reported that lesions of the arcuate nucleus that deplete brain levels of β-endorphin can disrupt some forms of stress analgesia (*29*). The demonstration of specific dexamethasone binding sites in the brain (*30*) suggests a means by which this drug could inhibit centrally released opioids and hence block the analgesic effect of prolonged, intermittent foot shock.

Our findings suggest that both opioid and nonopioid mechanisms underlie stress analgesia. To evaluate this hypothesis, studies are needed in which other criteria for opioid involvement (*16*) and other stressors are used. It will also be important in future work to assess the specificity of the analgesic effect of stress. Severe stress causes a constellation of physiological changes (thermoregulatory, motoric, hormonal, respiratory, and cardiovascular), some of which, like analgesia, have been found to be anatagonized by naloxone (*22, 25, 31*). The possibility that naloxone-sensitive stress analgesia is secondary to one or more of these other physiological effects cannot yet be dismissed.

Note added in proof: In work completed since this report was submitted, we found that rats receiving five daily injections of morphine (5 mg/kg) show less analgesia to prolonged, intermittent foot shock than saline-injected controls (*32*). The same morphine regimen does not affect analgesia to brief, continuous foot shock. This demonstration of cross-tolerance between the analgesic effects of morphine and the naloxone-sensitive (but not naloxone-insensitive) form of stress analgesia provides further evidence for the existence of opioid and nonopioid mechanisms of stress analgesia.

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Rings of Uranus: Proposed Model Is Unworkable

In a recent report (*1*), Van Flandern restates some of the difficulties with a conventional picture of Uranus's rings and proposes that they are the gaseous tails of unobserved small satellites. No quantitative support for this hypothesis is given; the only substantiation is a spectacular cover sketch. Van Flandern's hypothesis raises far more objections than it answers. A gaseous torus must have a minor diameter of thousands, not tens, of kilometers; very large densities are required to produce the postulated angles of refraction; and making up the mass losses, even with a generous lifetime, would use up quite a large body in a few million years.

In McDonough and Brice's study (*2*) of a possible torus associated with Titan, the minor diameter was found to be large, of the order of a Saturn radius or more. The ionized Io torus (*3*) is of a similar dimension. The difficulty with a very narrow torus can be readily illustrated, if we use the η ring of Uranus as an example; it has major and minor radii of

47,300 and 25 km (4). The gas in the torus can be thought of (5) as residing in a potential well with a restoring force per unit mass of $-g_0 s/r_0$ at a distance s from the center; r_0 and g_0 are, respectively, the radius of the central orbit and the planetary gravity there. The pressure and density vary according to a gaussian, $\exp(-s^2/X_0^2)$, where the scale radius $X_0 = (2r_0H_0)^{1/2}$ and $H_0 = kT/mg_0$; H_0 is the scale height at temperature T in a normal atmosphere at constant gravity, but in a torus the scale is given by the much larger X_0; k is Boltzmann's constant, and m is the mean atomic or molecular mass. For the η ring we take X_0 equal to 25 km, the observed minor radius; H_0 is then 6.6 m. With $g_0 = 279$ cm sec^{-2}, we find $m/T = 452$ atomic mass units (amu) per degree Kelvin. To fit the η ring with a gas of mass around 30 amu, the temperature would have to be 0.07 K; even with xenon, the requirement is 0.3 K. The other, narrower rings require even more unlikely conditions.

According to Van Flandern, the gaseous rings are to cast the observed shadows through refraction. A section of a torus can be regarded as a cylindrical lens; at distances greater than twice the focal length, there will indeed be a reduction of intensity of the occulted star. The paraxial focal length of the torus is easily found to be

$$f = X_0/(2\pi^{1/2}\nu_0)$$

where ν_0 is the refractivity (refractive index minus 1) of the gas at the center. This focal length would have to be less than half the Uranus-Earth distance, or less than 10 astronomical units; for the η ring, ν_0 would then have to exceed 4.7×10^{-9}. Most gases have a refractivity near 3×10^{-4} under standard conditions, where the density is, by definition, 1 amagat; the required density is therefore 1.6×10^{-5} amagat or 4.2×10^{14} atoms per cubic centimeter. The effective volume of the torus (5) is $2\pi r_0 X_0^2 = 5.8 \times 10^{21}$ cm^3; it therefore must contain 2.4×10^{36} atoms (or molecules), or 4×10^{12} moles of gas. If the molecular mass is near 30 amu, the total mass is 1.2×10^{14} g. A generous lifetime, as discussed below, would be 3×10^7 seconds, or an Earth year; if the torus must be replenished at the corresponding rate, a body of unit density and a radius of 10 km would be used up in 30,000 years, even if it were made entirely of frozen gas. Even at ten times the size, it would last only 30 million years.

To cast a shadow on Uranus itself, as Van Flandern suggests, the torus would require a focal length commensurate with the height of the ring. The required density is increased by a factor of 10^5, to well over 1 amagat.

The temperature of the emitted gas would be the same as that of the satellite, about 60 K. Even if it is not heated by the solar wind or magnetospheric plasma, the gas must absorb energy from the sun below about 1000 Å. The estimate previously given (5) for the Titan torus, scaled to Uranus's distance, gives a heating rate of 440 K per year. Even if the postulated torus did not expand initially far beyond the required dimensions, it would do so in much less than a year. The temperature reached in a year is enough to cause the gas to begin to dissipate away from Uranus's influence altogether (5). Any other heating or ionization processes would shorten the lifetime.

Although the problems outlined by Van Flandern are not solved, less radical approaches (6) are still preferable to the hypothesis of gaseous rings.

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Van Flandern (1) comments on the (3 ± 3 percent) albedo of the rings of Uranus. He asserts that "No known material in space meets this albedo constraint. It implies material reflecting less light than the blackest coal dust." We wish to point out that material in this albedo range was identified in various museum meteorite collections before 1973 (2) and on asteroid surfaces in space as early as 1971 (3). Additional examples include more than 76 percent of the asteroids (4), Phobos and Deimos (5) (the satellites of Mars), Amalthea (the fifth jovian satellite), as well as most interplanetary debris (6). Thus, in fact, most planetary objects with measured albedos exhibit albedos of 6 percent or less, and satisfy the constraint in question.

Moreover, Van Flandern's discussion of the supposed prototype for his hypothesis, the Io gas torus, is misleading. Instead of citing the extensive scientific literature on this topic (7), he references only a "news" article in *Sky and Telescope*. The densities of the various materials in the Io torus are very interesting for magnetospheric effects but are hardly sufficient for Van Flandern's purposes, since maximum ion densities in the torus are 10^2 to 10^3 cm^{-3} as compared with $\sim 10^{15}$ cm^{-3} in Earth's atmosphere at 100 km (the example of defocusing quoted). No optical effect of this torus has ever been detected during stellar occultations, including the Io occultation experiment that Van Flandern participated in (8). Thus any uranian torus would have to be many orders of magnitude denser than Io's and extraordinarily narrow (Io's torus has scales of 10^4 km or greater as opposed to 10^2 km required for Uranus).

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Van Flandern has proposed that the ring system of Uranus can be explained in terms of "a single body orbiting in each of the observed ring locations, which sheds gaseous material as it orbits" (1). In support of this contention, he mentions as analogies three phenomena found in the solar system: (i) sputtering of surface materials by energetic particles trapped in an intense magnetosphere; (ii) thermal diffusion of hydrogen from a satellite's atmosphere (Jean's escape); and (iii) the sublimation of frozen gases such as in comets. As Van Flandern notes, any gaseous material produced must diffuse rapidly (a year or so) from the satellite orbit and must be renewed continuously. In contention then is the rate at which gaseous material must be shed from a small body in orbit about Uranus in order for the gaseous ring theory to be operable.

The case of sputtering by energetic particles is dubious. Current models of the internal structure of Uranus, the almost complete absence of internally generated heat (*2*), and the lack of strong radio emissions from Uranus (*3*) preclude a magnetic field strong enough to produce large-scale sputtering. For the diffusion of atmospheric constituents (Jean's escape) into a satellite's orbit, a satellite at Uranus's distance would have to be more than 1000 km in diameter to maintain a long-lived atmosphere even for cosmochemically abundant heavy gases such as argon. Such a large satellite would already have been detected (*4*).

The rapid sublimation of frozen gases from solar insolation at 20 astronomical units is difficult to achieve since the typical subsolar blackbody temperature, T, is ~ 90 K; for highly reflecting (~ 90 percent) ice, $T \sim 50$ K. At these temperatures, the evaporation rates of all cosmochemically expected ices and icy clathrates are far too low to produce the required amounts of gas (*5*). Ices such as H_2O, NH_3, H_2S, and CO_2 are essentially stable over the age of the solar system, whereas ices such as CH_4, Ar, and N_2 are too unstable to last long. Clathrates such as $CH_4 \cdot XH_2O$ and $CO_2 \cdot XH_2O$ are very stable, but $N_2 \cdot XH_2O$ and $Ar \cdot H_2O$ are not and will be lost quickly. If evaporation does occur, a crust similar to that postulated to form on short-period comets would soon insulate the interior and further sublimation would be negligible.

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The comments by Hunten are well thought-out objections to certain aspects of my model on the rings of Uranus (*1*). Indeed, I am obliged to modify the model somewhat to meet his objections.

The essence of the model I proposed is that the rings consist of gaseous material originating from a single satellite in each ring. The dimming of the light of stars passing behind the rings must surely be due to refractive defocusing by gaseous material because the reflectivity of the material is too low to be consistent with any known solid material at the required densities. A single dominant satellite is required to account for the perplexing dynamical properties of the rings.

Recently Dermott and Murray (*2*) have demonstrated that very small satellites with masses less than 10^{-8} that of Uranus can maintain large numbers of particles in "horseshoe" orbits simulating rings and that such orbits are stable over the age of the solar system, even against radiation pressure. Their model accurately reproduces the most perplexing dynamical properties of the rings, including the eccentricity gradient of the ϵ ring. There is therefore one dominant satellite and a great deal of debris in each ring, the debris presumably originating from partial breakup of the satellite. It should be remembered that all uranian rings are well inside the Roche limit.

With the dynamical problems plausibly explained, the remaining open question is the cause of the low reflectivity of the material. If the albedo is as high as 3 to 4 percent, consistent with the darkest bodies observed in the solar system, then the ring debris may provide the entire explanation for the appearance of the rings. If it is less than 1 percent, as claimed in one experiment (*3*), then the refractive defocusing mechanism is still required; but now there are a great many bodies in the ring which can shed such gaseous material.

This alteration of my model seems to answer Hunten's objections. The gaseous material is dense only in the vicinity of the ring debris from which it originates but is not required to remain dense until it can spread out into a complete ring. The radiation pressure perturbations are now periodic, not secular, so that Hunten's lifetime estimates for gaseous particles do not apply.

Gradie's critique of my three examples of existing situations involving the shedding of gaseous material fails to observe that they are only examples; as I said in (*1*, p. 1076), "The mechanism for Uranus may or may not be similar to one of these three cases." Indeed, the presence of the ring debris inside the Roche limit is surely a factor in the production rate for gaseous material, which may occur at much lower rates in the revised model.

The comment by Fanale *et al.* makes sense only if the authors are unaware of the experiment I cited (*3*), which gave an albedo of "less than 1 percent of the corresponding albedo of Saturn's rings." Everyone would agree that there is nothing unprecedented about an albedo of 6 percent but 1 percent is a different story. My statement (*1*, p. 1076) that "No known material in space meets this albedo constraint" refers to the 1 percent figure. They further state (*4*, p. 626) that "No optical effect of this [Io's] torus has ever been detected during stellar occultations, including the Io occultation experiment that Van Flandern participated in." Although it is clearly possible that the optical effects I cited (*5*) in (*1*) had some other cause, I do not know how Fanale *et al.* can state with such unequivocal confidence that the unexplained irregularities which were observed had no relation to Io's torus. Indeed, they seem unaware of the existence of these observed anomalies.

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