process may not have been so smooth as initially thought, and numerical simulations performed by Tsiganis *et al*. (*4*) show that the passage of Jupiter and Saturn through a 2:1 resonance may have ignited a period of strong chaotic evolution of Uranus and Neptune. In this scenario, the two planets had frequent close encounters and may even have exchanged orbits before their eccentricities finally settled down, allowing a more quiet migration to the present orbits.

The presence of a thick disk of Trojans around Neptune is clearly relevant to understanding the dynamical evolution of the planet. The co-orbital Trojan paths are unstable when Neptune has repeated close approaches with Uranus, and the capture of the present population appears possible either at the time of the last radial jump related to an encounter with Uranus or during the final period of slow migration. In this last case, collisional emplacement—in synergy with the reduction of the libration amplitude attributable to the outward migration and by the mass growth of the planet—is the only viable mechanism for trapping Trojans in this phase, but it does not appear to be so efficient as to capture a large population. Moreover, the only frequent planetesimal collisions are those that are close to the median plane of the disk, and this fact is at odds with the presence of high-inclination Trojans such as the one found by Sheppard and Trujillo. A thick disk of Neptune Trojans seems also to rule out the possibility that Trojans formed in situ from debris of collisions that occurred nearby (*5*).

The chaotic capture invoked to explain the orbital distribution of Jupiter Trojans might have worked out in the same way for Neptune. The planet at present is close to a 2:1 mean-motion resonance with Uranus; however, the resonance crossing has not been reproduced so far in numerical simulations of the migration of the outer planets. Alternatively, some sweeping secular resonance might have provided the right amount of instability for the "freeze-in" trapping to occur. In the near future, after additional Neptune Trojans are detected, an important test would be to look for a possible asymmetry between the trailing and leading clouds. Theoretical studies have shown that the L5 Lagrangian point (the trailing one) is more stable in the presence of outward radial migration and that this asymmetry strongly depends on the migration rate. This finding would have direct implications for the capture mechanism and for the possibility that the outward migration of Neptune was indeed smooth, without fast jumps caused by gravitational encounters with Uranus.

Sheppard and Trujillo also sort out another aspect of the known Neptune Trojans: their optical color distribution. It appears to be homogeneous and similar to that of Jupiter Trojans, irregular satellites, and possibly comets, but is less consistent with the color distribution of KBOs as a group. This finding raises questions about the compositional gradient along the planetesimal disk in the early solar system, the degree of radial mixing caused by planetary stirring, and the origin of the Jupiter and Neptune Trojans. Did Trojans form in a region of the planetesimal disk thermally and compositionally separated from that of the KBOs? How far did the initial solar nebula extend to allow important differences among small-body populations? Additional data are needed to solve the puzzles of the dynamical and physical properties of Neptune Trojans, and the finding by Sheppard and Trujillo is only the first step.

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CLIMATE CHANGE

Can We Detect Trends in Extreme Tropical Cyclones?

Subjective measurements and variable procedures make existing tropical cyclone databases insufficiently reliable to detect trends in the frequency of extreme cyclones.

Christopher W. Landsea, Bruce A. Harper, Karl Hoarau, John A. Knaff

Recent studies have found a large, sudden increase in observed tropical cyclone intensities, linked to warming sea surface temperatures that may be associated with global warming (*1*–*3*). Yet modeling and theoretical studies suggest only small anthropogenic changes to tropical cyclone intensity several decades into the future [an increase on the order of ~5% near the end of the 21st century (*4*, *5*)]. Several comments and replies (*6*–*10*) have been published regarding the new results, but one key question remains: Are the global tropical cyclone databases sufficiently reliable to ascertain long-term trends in tropical cyclone intensity, particularly in the frequency of extreme tropical cyclones (categories 4 and 5 on the Saffir-Simpson Hurricane Scale)?

Tropical cyclone intensity is defined by the maximum sustained surface wind, which occurs in the eyewall of a tropical cyclone over an area of just a few dozen square kilometers. The main method globally for estimating tropical cyclone intensity derives from a satellite-based pattern recognition scheme known as the Dvorak Technique (*11*–*13*). The Atlantic basin has had routine aircraft reconnaissance since the 1940s, but even here, satellite images are heavily relied upon for intensity estimates, because aircraft can monitor only about half of the basin and are not available continuously. However, the Dvorak Technique does not directly measure maximum sustained surface wind. Even today, application of this technique is subjective, and it is common for different forecasters and agencies to estimate significantly different intensities on the basis of identical information.

The Dvorak Technique was invented in 1972 and was soon used by U.S. forecast offices, but the rest of the world did not use it routinely until the early 1980s (*11*, *13*). Until then, there was no systematic way to estimate the maximum sustained surface wind for most tropical cyclones. The Dvorak Technique was first developed for visible imagery (*11*), which precluded obtaining tropical cyclone intensity estimates at night and limited the sampling of maximum sustained surface wind. In 1984, a quantitative infrared method (*12*) was published, based on the observation that the temperature contrast between the warm eye of the cyclone and the cold cloud tops of the eyewall was a reasonable proxy for the maximum sustained surface wind.

In 1975, two geostationary satellites were available for global monitoring, both with 9-km resolution for infrared imagery. Today, eight

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