# Kuiper Belt woes for accretion disk models

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Kuiper Belt Objects (KBOs) are named after Dutch astronomer Gerald Kuiper (1905–1973). In 1951, he had proposed a source beyond Neptune to replenish the short-period comets which would have decayed if the solar system were billions of years old.[1,2] Research on the KBOs has turned up many unexpected features.[3]

For one thing, they are much too large to be embryonic comets.[4] Also, there are far too few KBOs to account for the hoped-for source of short period comets.[5] Therefore, many astronomers refer to the bodies as Trans-Neptunian Objects (TNOs), which objectively describes their position beyond Neptune without any *assumptions* that they are related to the comet source Kuiper had hoped for.

Other surprises include the combination of *Plutinos, Classical Kuiper Belt Objects* (CKBOs) and *Scattered Disk Objects* (SDOs). Plutinos are objects with high eccentricity near the orbit of Pluto. The CKBOs have low eccentricity and generally low-inclination orbits while the SDOs have higher eccentricities and inclination. Both of these latter groups are located well beyond the orbit of Pluto. The challenge for evolutionary astronomers has been to account for these two populations of objects within the classic accretionary disk model, in which a disk of gas and dust collapses over millions of years to form the solar system.

## 'Migrating' planets and planetesimals

One theoretical computer simulation postulates that these observations can be explained if Neptune and the Kuiper Belt actually *formed much closer* to the sun.[6,7] Gravitational interactions between Neptune and the surrounding dense disk of gas, dust, and small protoplanets or planetesimals supposedly drove them out to their current orbits in the late stages of solar system formation. In other words, the solar system supposedly formed in a truncated disk up to 30 AU[8] in diameter, while the current solar system reaches out to about 50 AU. It is interesting that at 30 AU, even Neptune could not have formed in the accretionary disk because the dust and gases would have been much too thin.[9] The Kuiper Belt objects could not have formed either. So, Neptune and the TNOs are believed to have formed at 20 AU in a denser disk.

Interactions between Neptune and planetesimals are proposed to have caused Neptune to migrate outward and resulted in the disappearance of practically all of the original planetesimals. This latter aspect is supposed to have been caused by the gravity of Neptune either throwing planetesimals out into interplanetary space or closer to the sun, in which case the planetesimals encountered other planets. The remaining planetesimals beyond Neptune became the TNOs. All of this activity is supposed to have taken about 10 million years.[10]

The key to this hypothesis is that Jupiter, the largest and innermost of the giant planets, would have acted as an anchor. This situation supposedly would have enabled angular momentum transfer between the planetesimals on the one hand and Saturn, Uranus and Neptune on the other, resulting in the outward migration of the three planets.

Although the idea of outward orbital migration of Neptune and planetesimals is not new,[11] the computer simulation supposedly explains several of the mysteries of outer solar system formation. These mysteries include the formation of Neptune, the low mass in the Kuiper Belt, the failure of the planetesimals in the Kuiper Belt to form a planet, the outward migration of the outer solar system, and the simultaneous formation of CKBOs and SDOs. The 'outward migration of the outer solar system' is a hypothesis, not an observed fact, whereas the co-existence of CKBOs and SDOs is an observation. There are various hypotheses to explain the latter.[2] The CKBOs, SDOs and Plutinos need to have formed simultaneously in these evolutionary hypotheses, except that most hypotheses assume the CKBOs to be the parent population of the others.

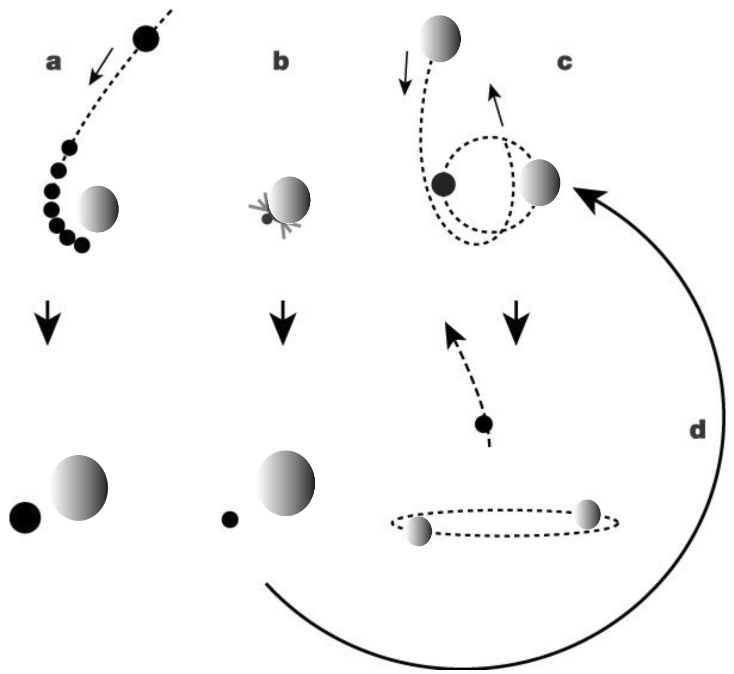
One wonders if all these phenomena could really occur in a real world accretion disk, or whether they are the result of a subjective, carefully adjusted computer simulation. The accretion disk model needs these *ad hoc* additions for the model to be valid. It is possible that the outward migration and the thinning of planetesimals would not work with a more realistic accretion model, which could indicate that the ten million years never existed and that the solar system was created. Regardless, new problems have arisen for the accretion disk hypothesis from the computer simulation:

> 'Of course, this new set of ideas raises further questions. The main one is, how could the primordial Solar System be formed in a truncated disk? … what conditions could cause this truncation of a developing planetary system?'[12]

## The binary problem

It seems that the more we know about the TNOs, the more challenging it becomes for the formation of the solar system by an accretionary disk. Recently, it has been observed that anywhere between 2% and 10% of the 800 TNOs discovered so far are binary.[4,13,14] Most perplexing, the components of the binaries are nearly the same size and move on highly elongated orbits around each other. These orbits can be hundreds to thousands of times as long as the radii of the planetesimals. This situation contrasts with binary asteroids between Mars and Jupiter that are made up of tiny companions tightly bound to a much larger partner in circular orbits.

There are several standard mechanisms suggested for the formation of




*The standard mechanisms suggested for the formation of binaries are: a) tidal disruption of one object followed by coagulation of fragments during a close encounter with the other, and b) a giant impact, where collision debris coagulates into a 'moon'. Since these do not explain Kuiper Belt binaries, a new hypothesis has been proposed involving three-body interactions (c). It is speculated that the two larger objects eject the smaller object and end up in a binary orbit of high eccentricity (d), but there are problems. (After ref. 13, p. 518).*

binaries. However, they seem to be of little help in explaining the Kuiper Belt binaries. For instance, the idea that such binaries in the Kuiper Belt formed in the early solar system from objects orbiting the sun in tandem is ruled out because of the odds against such an occurrence. A second mechanism—collisions that would have formed one large and at least one small body (the first stage in the new hypothesis)—is not likely either because there is too much angular momentum in the Kuiper Belt binaries. A collision that could end up with this much angular momentum would have totally destroyed and dispersed the colliding bodies.[8]

So, the new hypothesis for the evolution of TNO binaries suggests that these binaries were formed by three-body interactions. In this case a 'normal' binary with a large and small object is first formed. Then this binary system is approached by an object with close to the same mass as the larger companion. The elaborate interaction between the two large objects and the small object ends up ejecting the smaller object, so that the two large objects end up in a binary orbit of high eccentricity (see figure).

However, there are significant problems with this hypothesis. There are no known mechanisms for actively creating binary systems at present, while binaries are being destroyed by energetic impacts that shatter the bodies and disperse the fragments. Therefore, it is assumed that binaries must have been more numerous in the past.[15]

Furthermore, binaries that were supposedly formed in the early solar system could have been destroyed by less catastrophic collisions and close flybys of other TNOs that weaken the orbital bond of binaries, especially the bodies that are already weakly bound or where one object is small. This is where the original density of the outer reaches of the early solar system in the accretion model becomes crucial. Caution is urged in accepting the new theoretical model for the formation of the strange TNO binaries:

> 'But caution should be the watchword when theoreticians interpret observational data before developing formation models.'[15]

Regardless of whether the new hypothesis is workable, the more astronomers know about the Kuiper Belt, the more strain is put on accretionary disk models for the origin of the solar system, and the more the solar system has the appearance of being created unique.

## References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