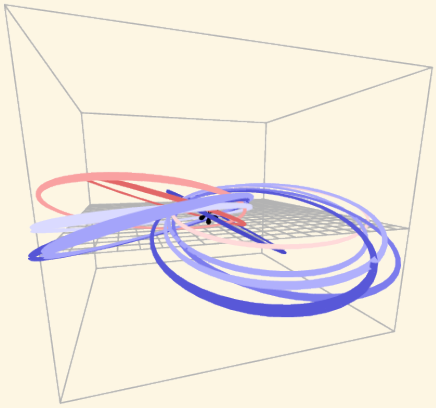
# Do We Need Planet 9?

*Ann-Marie Madigan & Mike McCourt*

## Introduction



As more and more distant minor planets—like Pluto—are being found, it's become clear that they follow **oddly aligned** orbits. Rather than being randomly tilted, their orbits:

- Have **high inclinations** (tilted well out of the ecliptic)
- Are **clustered** in argument of pericenter $\omega$, collectively forming a **cone-like structure**

These patterns are difficult to explain with classical planetary dynamics. So—what's going on in the outer solar system?

## Two Competing Explanations

### Planet 9 Hypothesis

In order to explain the minor planet orbits, some authors propose that a massive, undiscovered Neptune-sized planet shepherds these orbits into alignment through long-term gravitational influence. This hypothesis:

- ✓ Explains clustering in $\omega$
- ✗ Requires a carefully tuned, unseen object
- ✗ Doesn't naturally explain the **high inclinations**

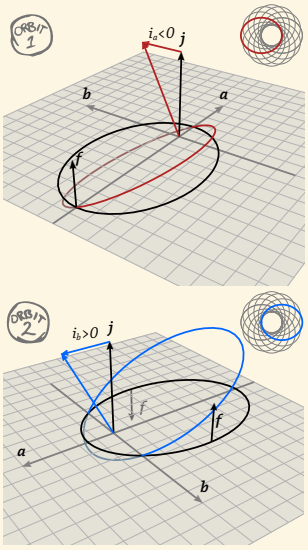
In addition, the Planet 9 hypothesis feels ad-hoc; it is post-dictive, not pre-dictive.

### The Inclination Instability

Ann-Marie Madigan identified a new **gravitational instability** in nearly radial disks of objects like the minor planets. The key features:

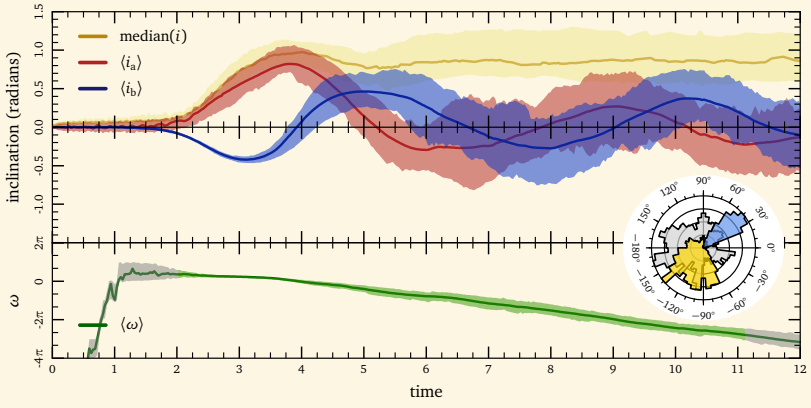
- ✓ Drives *exponential growth* in inclination
- ✓ Causes *coherent clustering* in argument of pericenter
- ✓ Converts a disk into a **cone**

This isn't driven by a central planet, but by the **collective self-gravity** of the disk acting over long timescales. It should always be active, and requires no ad hoc assumptions.




Depiction of the instability in an idealized,"two-orbit" toy model. The top right of each panel shows the location of the orbit in the disk from a face-on perspective. Top panel: orbit 1 experiences a net upward force $\vec{f}$. This force produces a torque along the $\hat{b}$ axis, rotating the orbital plane such that $i_a < 0$.

## Dynamics of the Inclination Instability




In $N$-body simulations, the inclination instability naturally reproduces the key properties observed in minor planets: the **high inclinations**, **cone-like structure**, and **clustering in** $\omega$. Entirely as a consequence of gravity!

**We may not need Planet 9 after all—the minor planets organize themselves.**

## References

*Madigan & McCourt (2016), Madigan et al. (2018)*