ASTR 405
Planetary Systems
Evolution of Planetary Systems

Fall 2025

Prof. Jiayin Dong

Supplementary Readings: **formation.pdf Section IV** on Canvas

Lecture Notes on the Formation and Early Evolution of Planetary Systems by Armitage

Module II: Exoplanet Demographics and Planet Formation

- **Protoplanetary Disks:** Gas–dust disks around young stars; evolve on Myr timescales, set the initial conditions for planet formation

- **Dust, Pebbles, and Planetesimals:** Dust grains stick → pebbles (mm–cm); rapid drift & instabilities lead to km-scale planetesimals

- **Planet Formation: Terrestrial and Giant Planets**

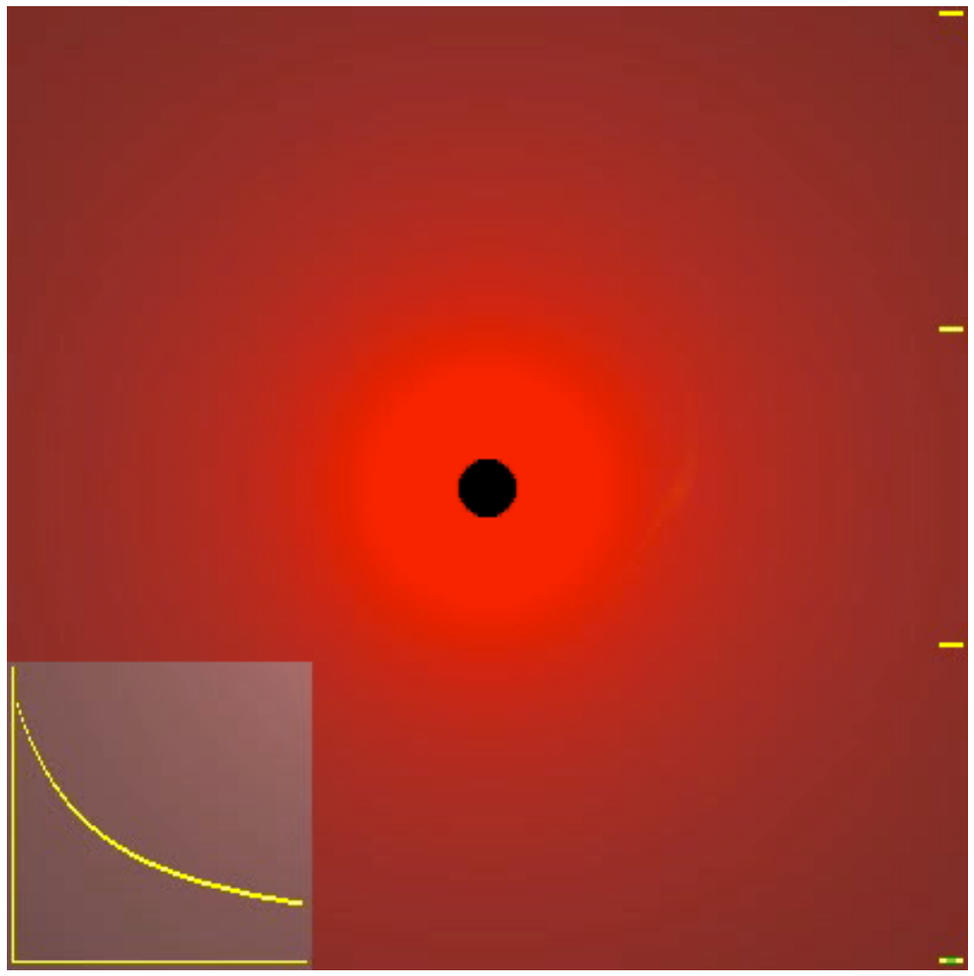
  Terrestrials: runaway/oligarchic growth → embryos → giant impacts

  Giants: ~10 $M_\oplus$ cores accrete gas before disk dispersal or via disk instability

- **Evolution of Planetary Systems:** Migration, resonances, and instabilities sculpt exoplanet architectures

Type I & II Migration

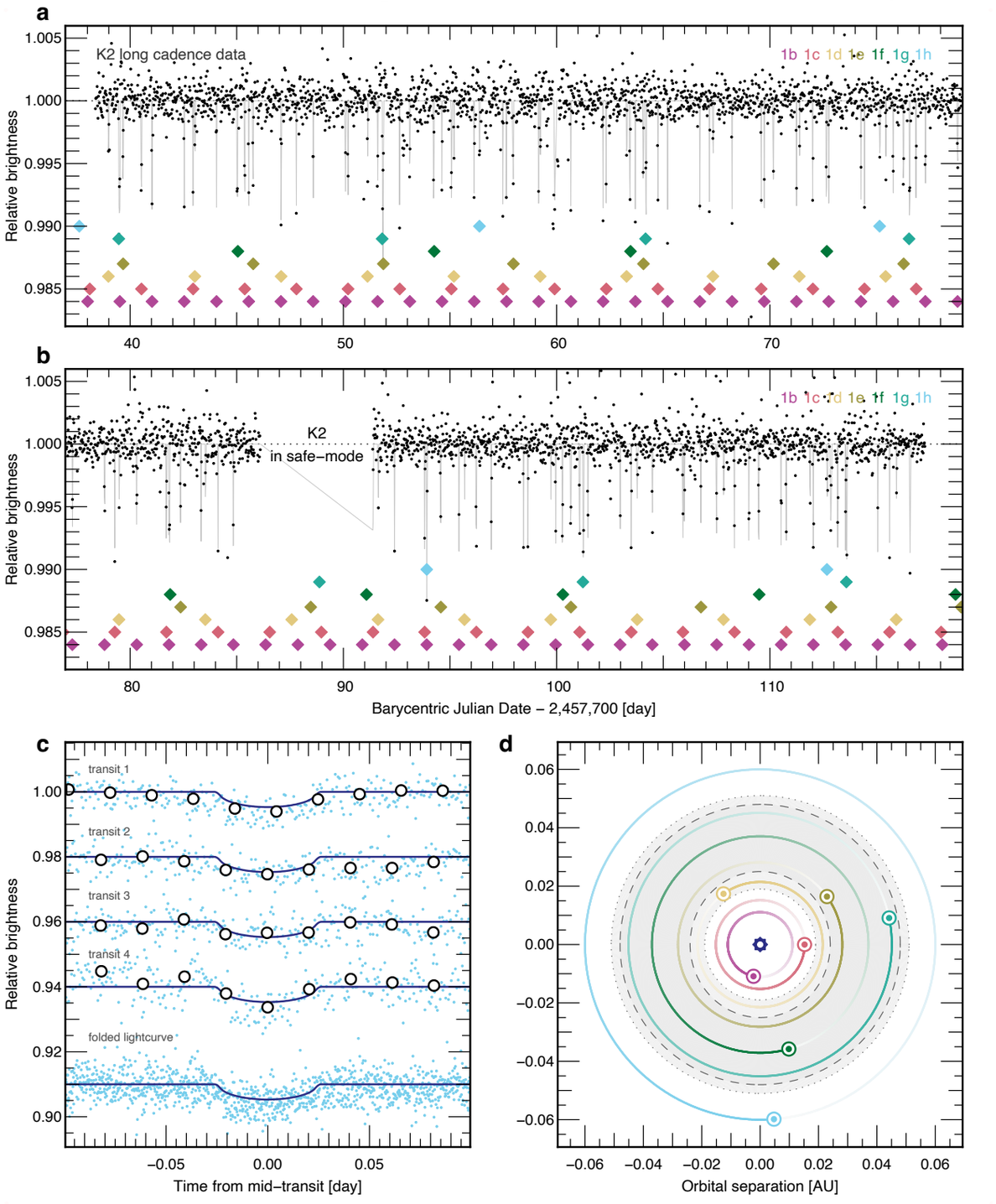
- **Type I migration**: **Low-mass** planet embedded in the gas disk feels torques from spiral density waves, causing rapid inward migration.
- **Type II migration**: **Massive** planet opens a gap and migrates inward on the disk's viscous timescale, moving with the disk gas.



Credit: P. Armitage

Orbital Resonance

TRAPPIST 1: 7-planet resonant chain (Luger+17)

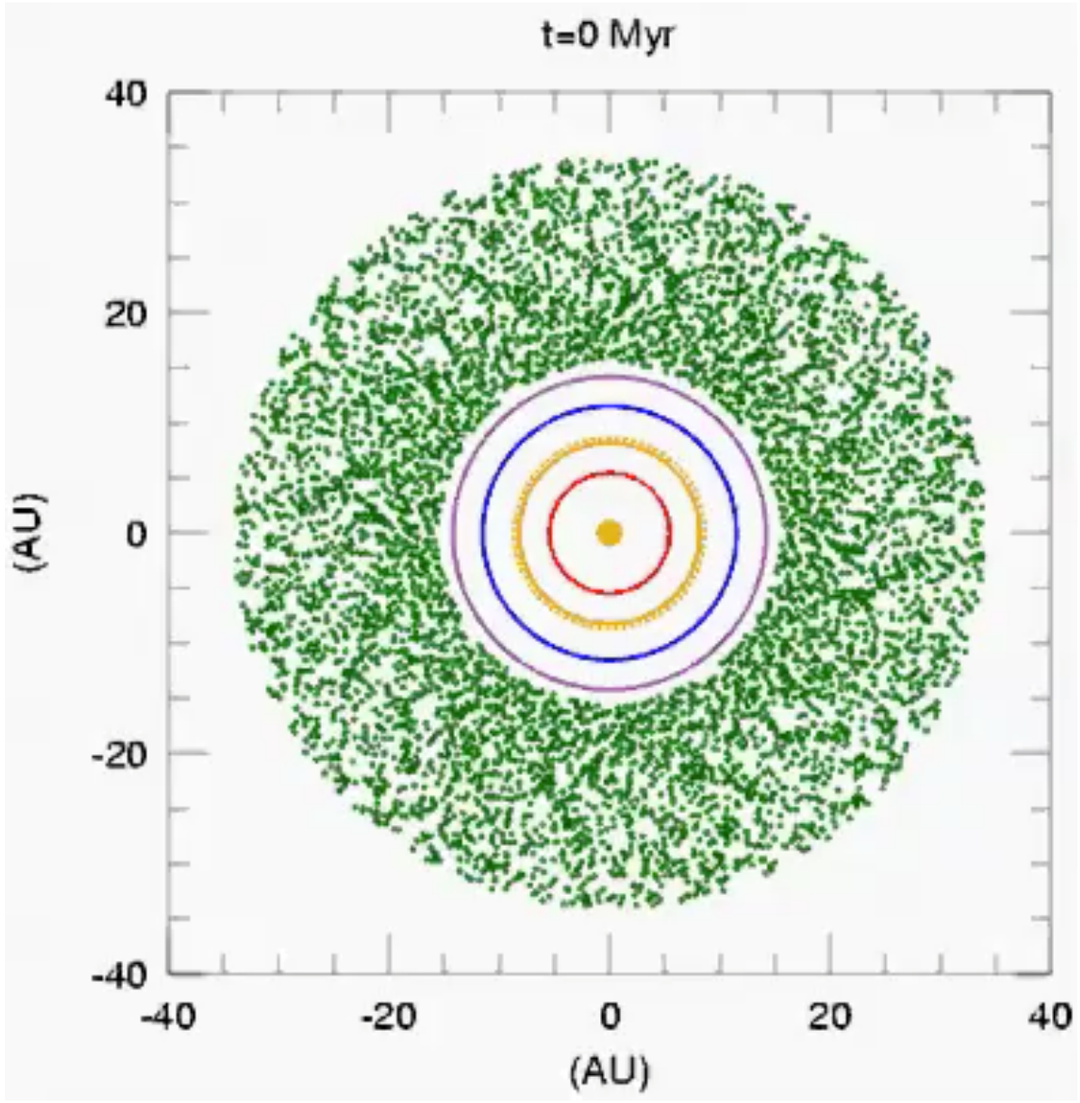


Outcome of migration

- Converging planetary orbits during migration can trap planets into mean-motion resonances, forming a **resonant chain**.

A resonant chain is a sequence of planets whose orbital periods are in simple integer ratios (e.g., 2:1, 3:2), maintaining stable gravitational interactions that lock their motions together.

The Nice Model for Solar System Evolution

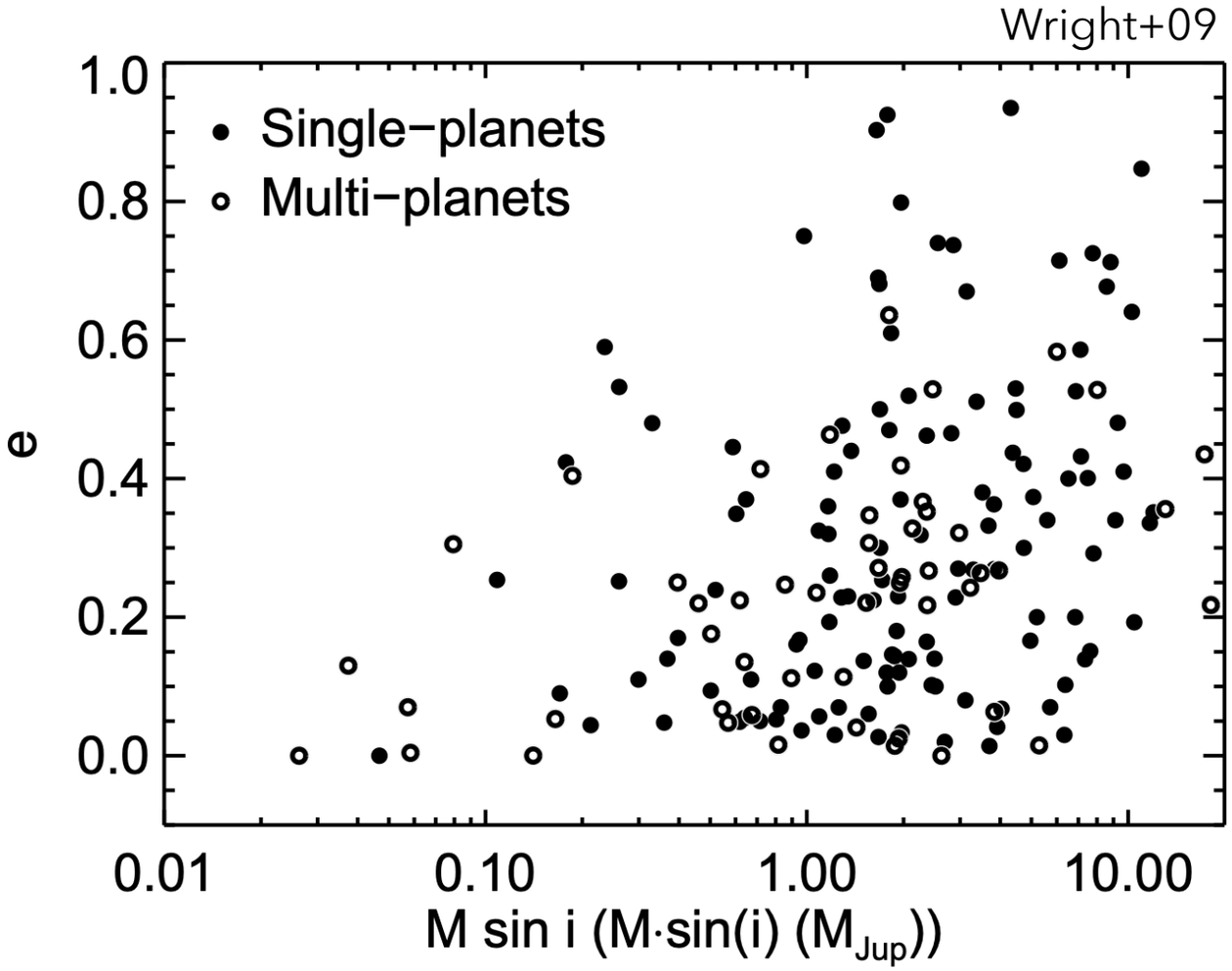


Credit: H. Levison

1. Giant planets initially formed in a more compact configuration within ~15 au.
2. Interactions with a massive outer planetesimal disk caused gradual migration. Jupiter moved slightly inward, while the others moved outward.
3. A Jupiter–Saturn resonance crossing triggered orbital instability, scattering Uranus and Neptune outward and reshaping the Kuiper Belt.

Planet–Planet Scattering

Gravitational encounters between massive planets after disk dispersal can eject planets, excite eccentricities, or tilt orbits.



Planet-planet scattering explains the high eccentricities and diverse orbital architectures seen in many exoplanet systems.