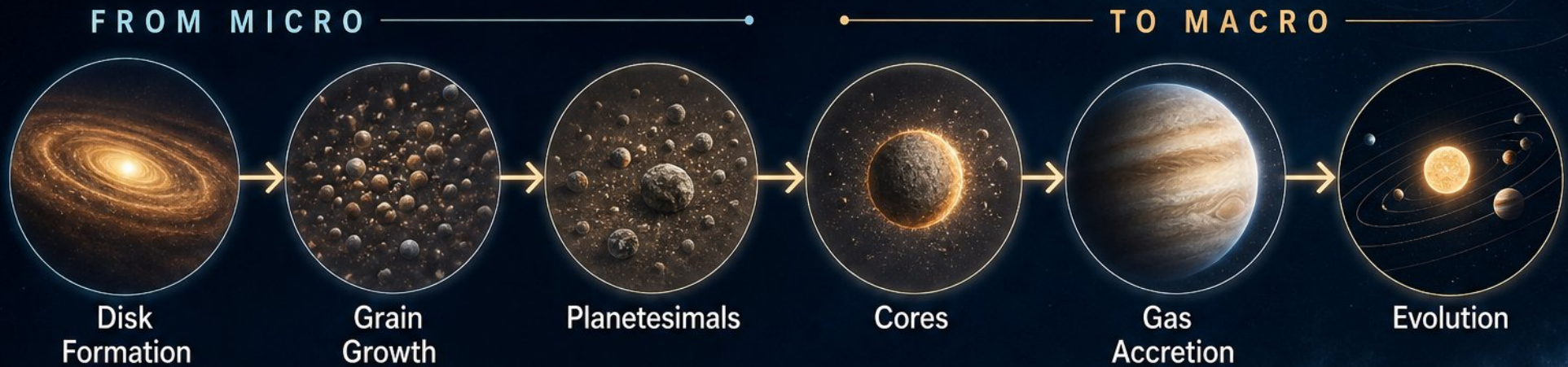


# How Planetary Systems Form

- - From gas and dust clouds to planets: a bottom-up process
- - Spanning micron-sized grains to full planetary systems
- - Course arc: disks and dust to exoplanet demographics
- - Essential for educators, students, and science communicators



# A Bottom-Up Story: The Modern Planet Formation Paradigm

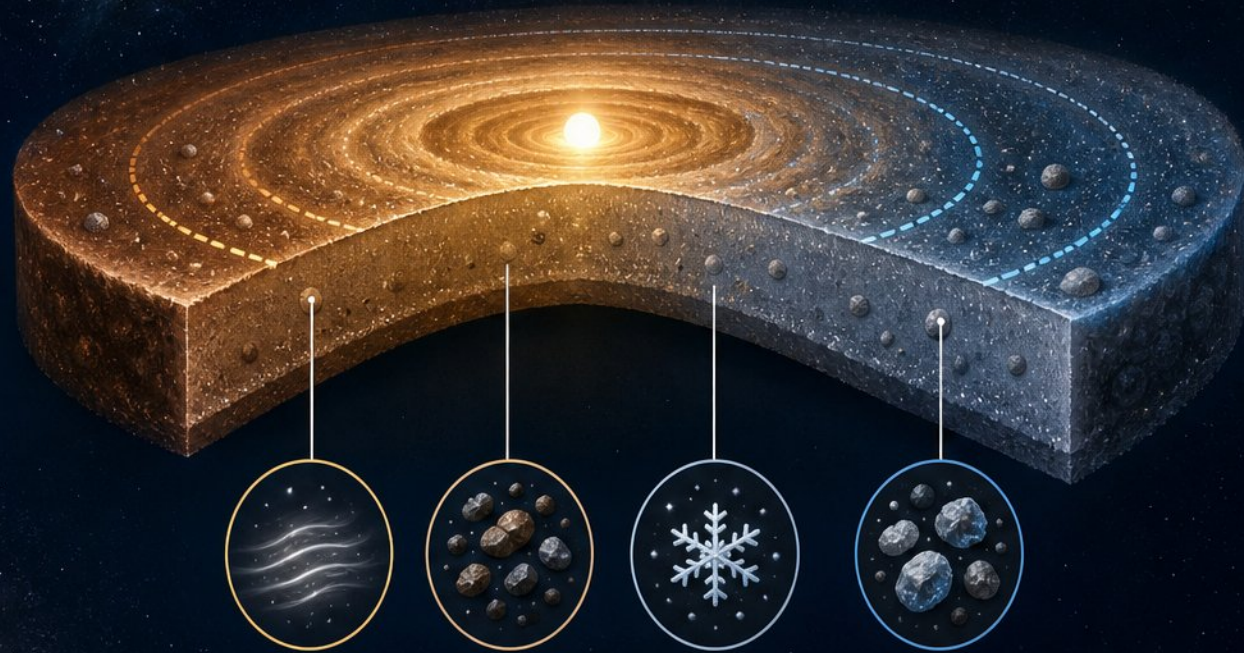


- Standard model: disk formation, grain growth, planetesimals, cores, gas accretion, evolution
- Consensus picture is still actively tested and revised
- Three evidence streams: Solar System, exoplanets, protoplanetary disk imaging
- Key open questions motivate the rest of the course

# Starting Ingredients: Molecular Clouds and Protoplanetary Disks

## — DISK AS LABORATORY —

- Molecular clouds collapse under gravity, forming stars and rotating disks
- Disks contain gas, submicron dust, and icy mantles
- Building materials: gas, refractory dust, volatile ices
- Temperature gradients create condensation fronts and snowlines



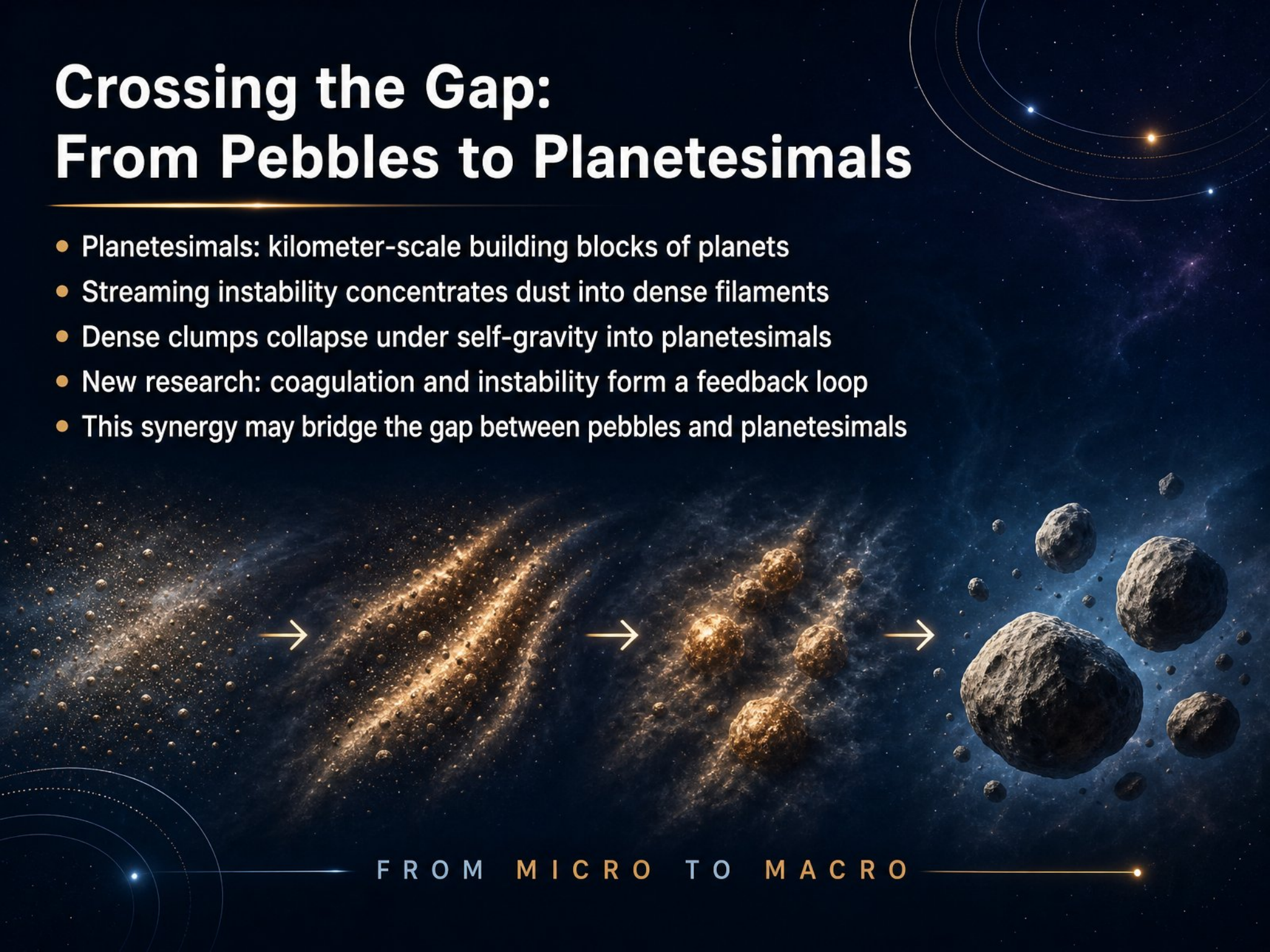
# Dust Growth and the First Big Hurdle

- Micrometer dust grains collide and stick into pebbles
- Growth barriers: bouncing, fragmentation, radial drift
- Stokes number measures dust–gas coupling
- Fast collisions shatter grains, halting growth



# Crossing the Gap: From Pebbles to Planetesimals

- Planetesimals: kilometer-scale building blocks of planets
- Streaming instability concentrates dust into dense filaments
- Dense clumps collapse under self-gravity into planetesimals
- New research: coagulation and instability form a feedback loop
- This synergy may bridge the gap between pebbles and planetesimals

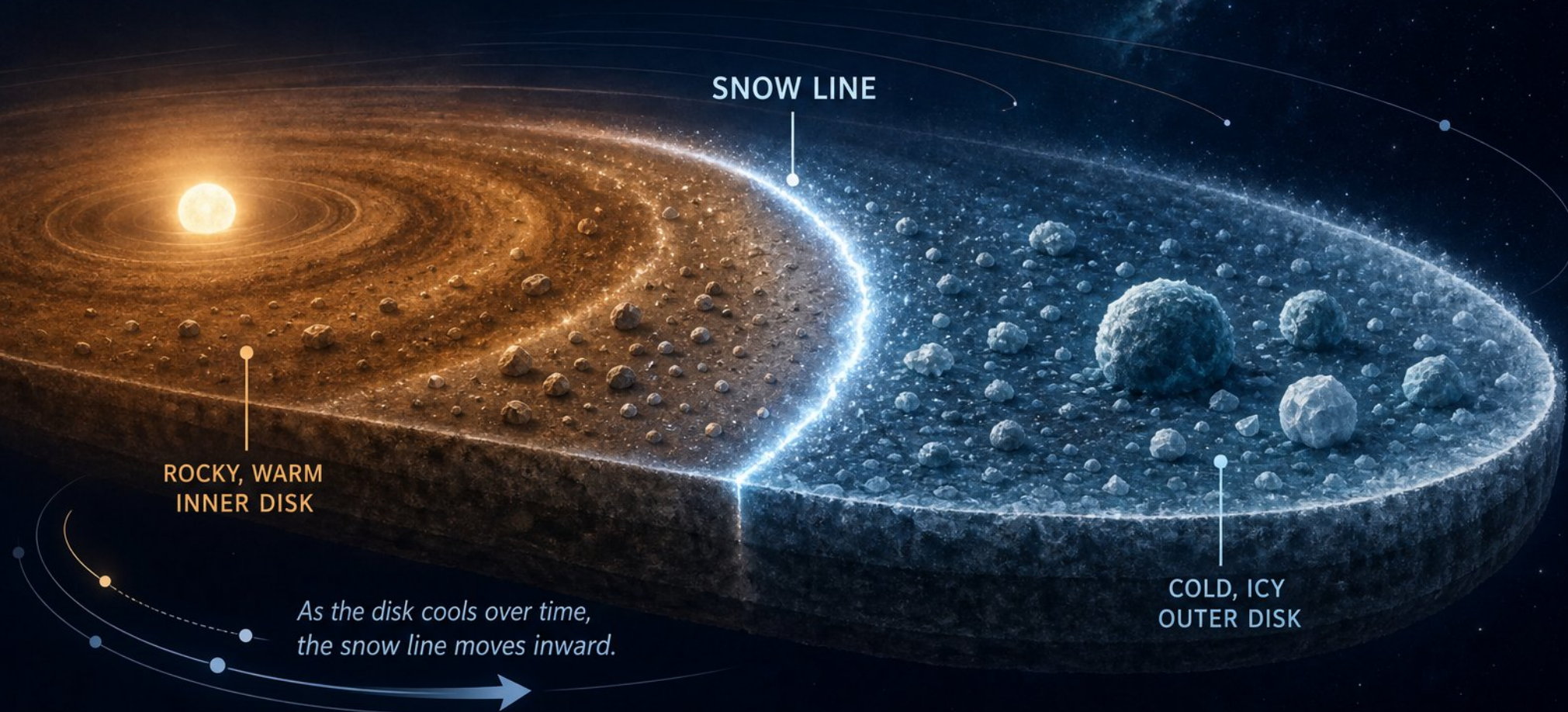


FROM MICRO TO MACRO

# The Snow Line and Disk Chemistry



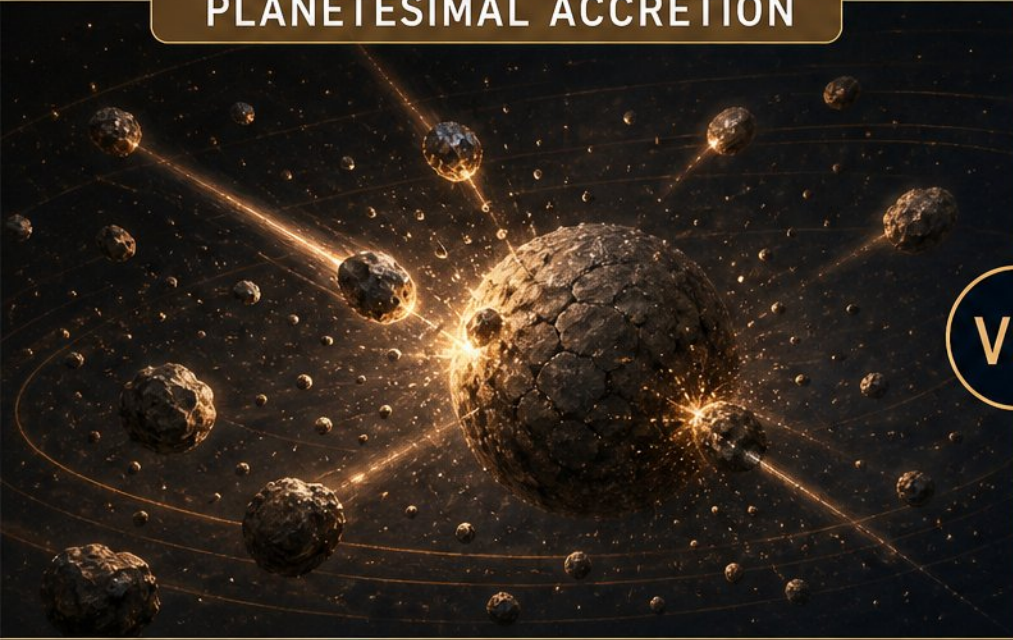
- - Boundary where water freezes onto dust grains
- - Boosts solid mass and grain stickiness beyond it
- - Favored site for planetesimal and giant planet formation
- - Position shifts inward as the disk cools and evolves



# Building Cores: Planetesimal Accretion and Pebble Accretion

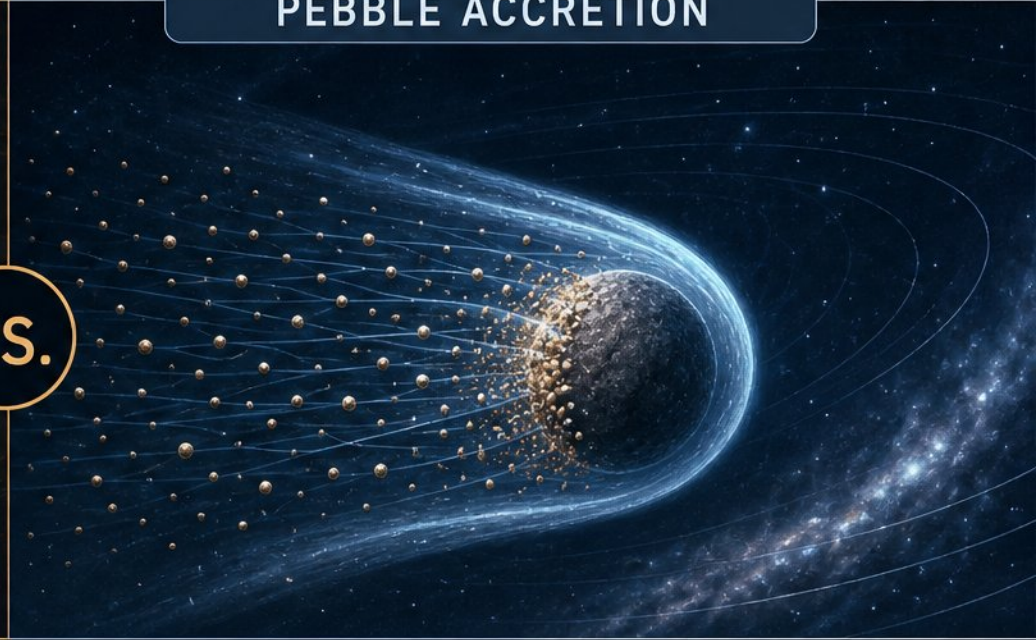
Collision-Dominated Evolution

## PLANETESIMAL ACCRETION



VS.

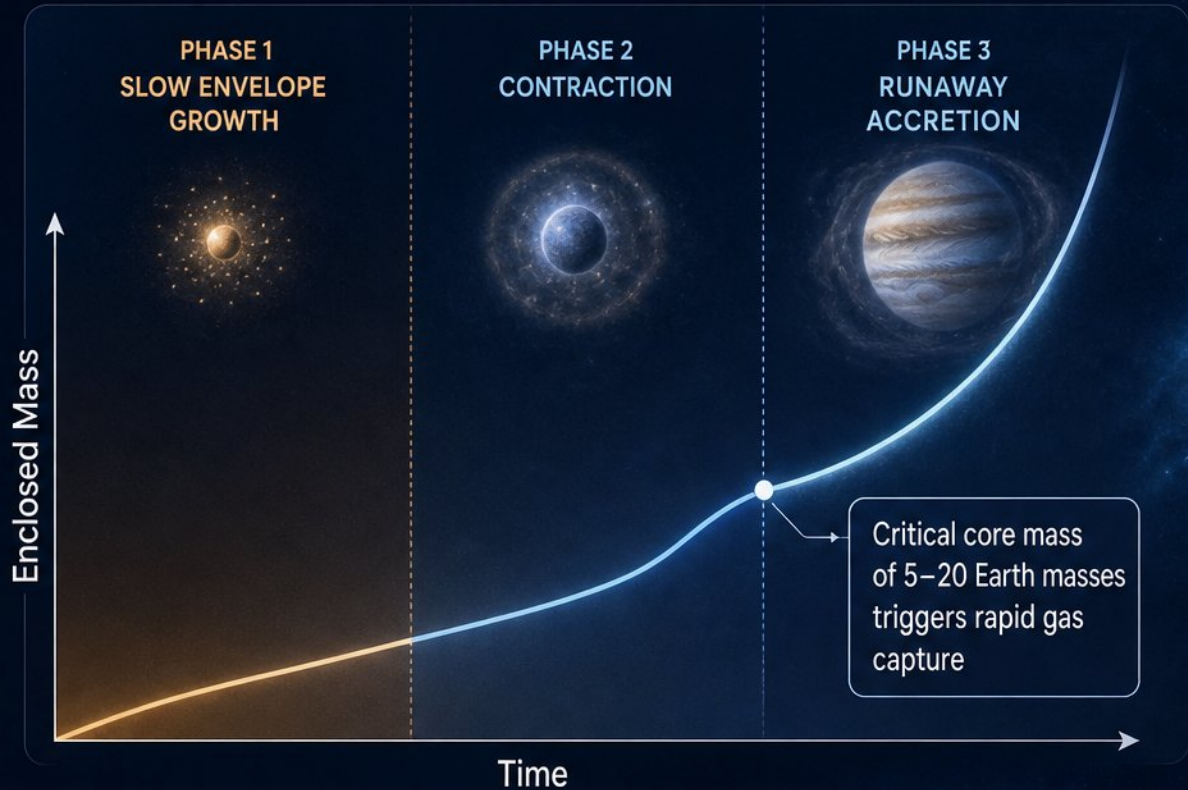
## PEBBLE ACCRETION



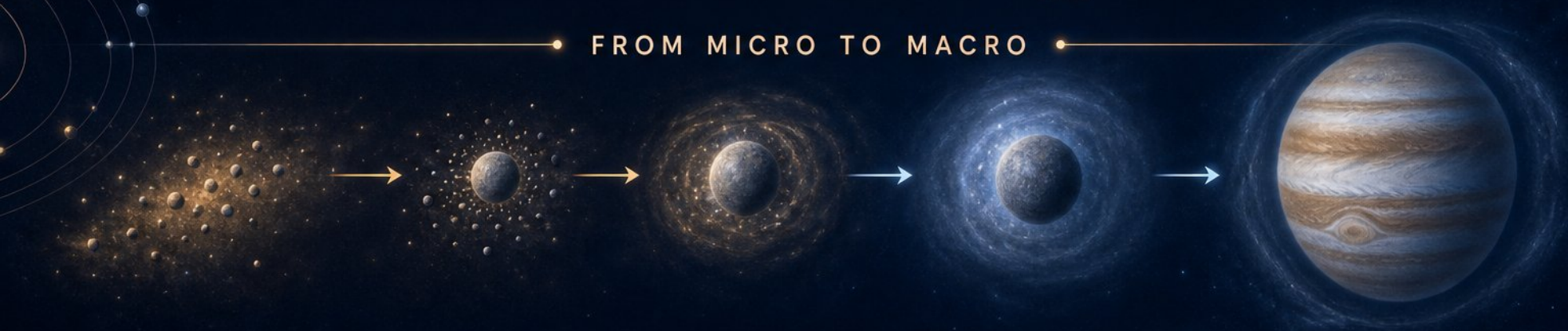
- - Planetesimal accretion: gravitational collisions of km-scale bodies
- - Pebble accretion: aerodynamic drag captures small particles efficiently
- - Oligarchic growth yields protoplanets from competing embryos
- - Hybrid models combine both mechanisms at different stages
- - Gravitational focusing and drag accelerate core assembly

# From Rocky Cores to Gas Giants

- – Core accretion: solid core forms first, then captures gas
- – Three phases: slow envelope growth, contraction, runaway accretion
- – Critical core mass of 5–20 Earth masses triggers rapid gas capture
- – Alternative: gravitational instability in massive, cool disks
- – Giant planet–host star metallicity link supports core accretion



FROM MICRO TO MACRO



# Planetary Migration and Orbital Architecture

- Planet-disk torques drive Type I and Type II migration
- Migration captures planets into resonant chains
- Hot Jupiters often form via disruption of these chains
- Period ratios reveal migration's fingerprints
- Disk dispersal triggers instability in resonant chains



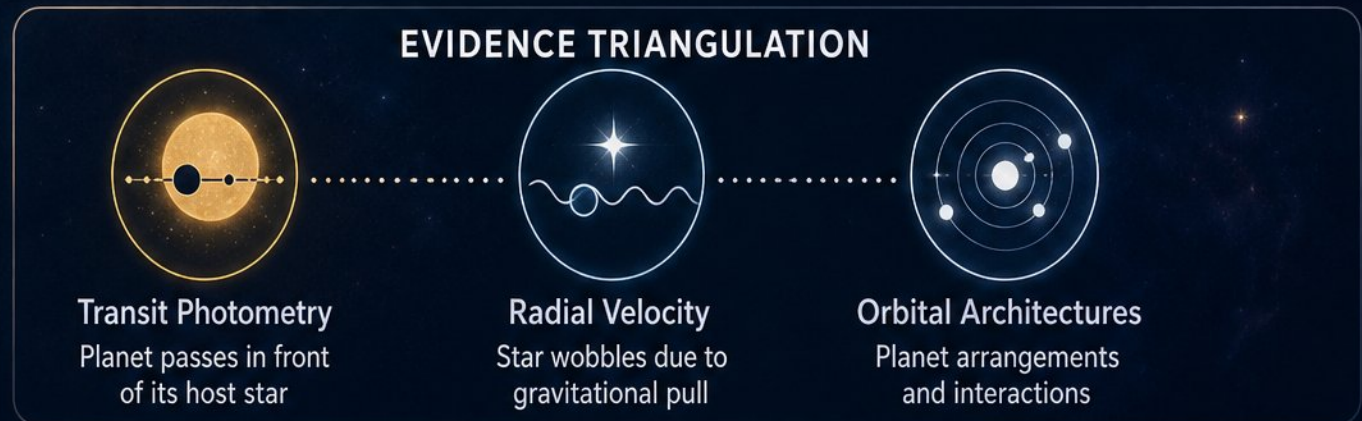
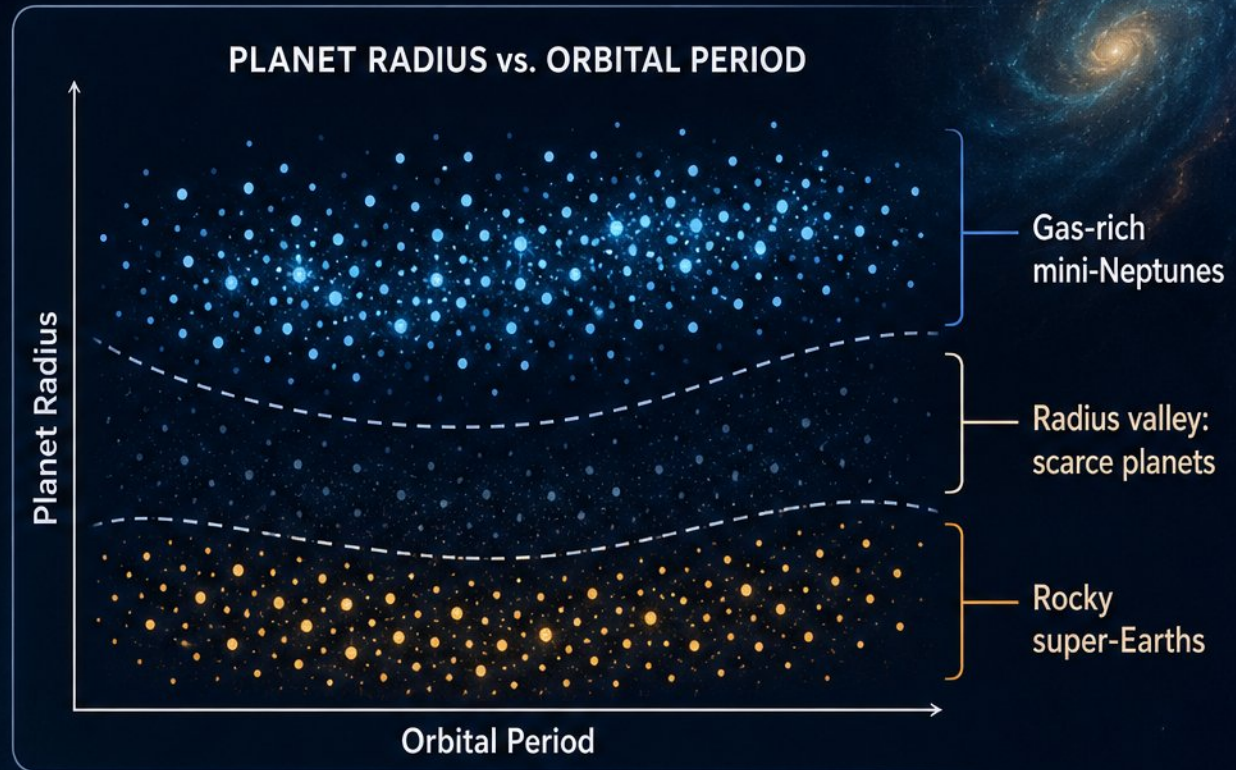
# Late-Stage Evolution: Impacts, Debris Disks, and Dynamical Sculpting

- Protoplanetary disks disperse, leaving planetary systems and debris disks
- Collisional cascades grind planetesimals into observable dust
- Giant impacts, like the Moon-forming collision, shape planetary bodies
- Dynamical instabilities rearrange young systems and trigger bombardments



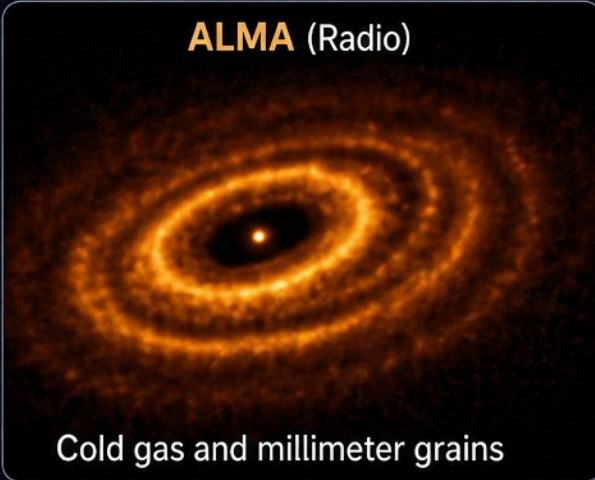
# What Exoplanets Teach Us About Formation

- Transit, radial velocity surveys reveal demographic biases
- Radius valley: rocky super-Earths vs. gas-rich mini-Neptunes
- Orbital architectures constrain formation and migration models
- Exoplanet diversity challenges Solar System-inspired predictions
- Super-Earths and mini-Neptunes: distinct formation pathways



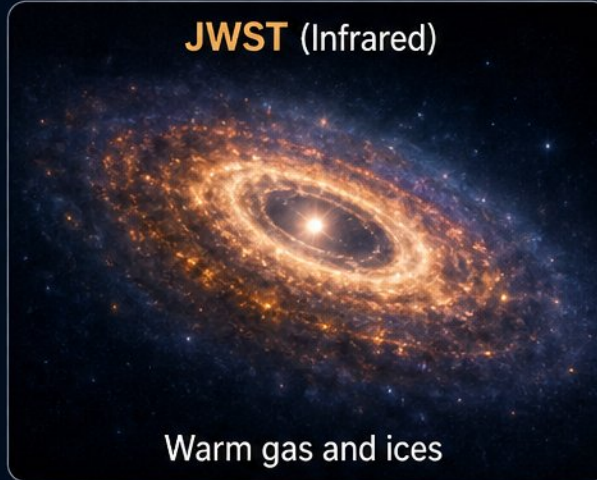
# Observing Planet Formation in Real Time

**ALMA** (Radio)



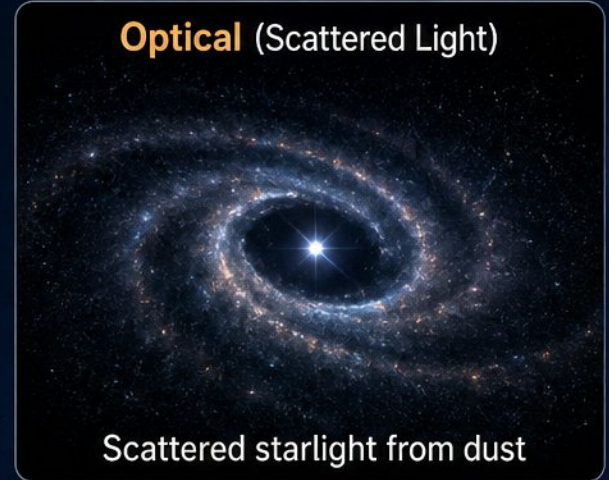
Cold gas and millimeter grains

**JWST** (Infrared)



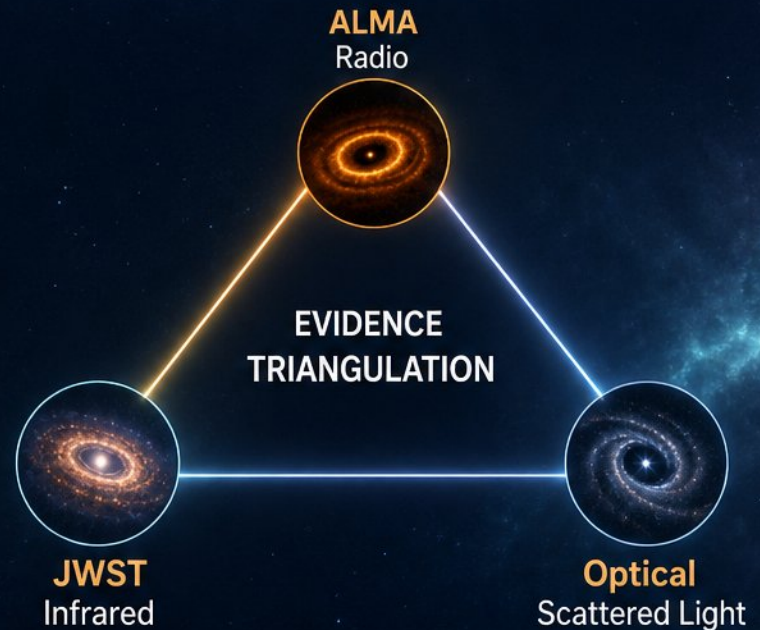
Warm gas and ices

**Optical** (Scattered Light)



Scattered starlight from dust

- ALMA maps dust rings and gaps; JWST probes inner disk chemistry
- Radio sees cold gas and millimeter grains; infrared traces warm gas and ices
- Rings, gaps, spirals, cavities signal embedded planets
- Links disk structures to formation stages (e.g., PDS 70)



# Common Misconceptions and Conceptual Pitfalls



- Students often link planet formation to the Big Bang



- Confusions about gravity, scale, and planet definitions



- Weak prior knowledge blocks deeper understanding



- Use the Planet Formation Concept Inventory to target gaps



- Active learning strategies improve conceptual gains



# Teaching and Communicating Planet Formation



- Use Lecture-Tutorials for active learning and higher gains



- Address common misconceptions, like confusing formation with the Big Bang



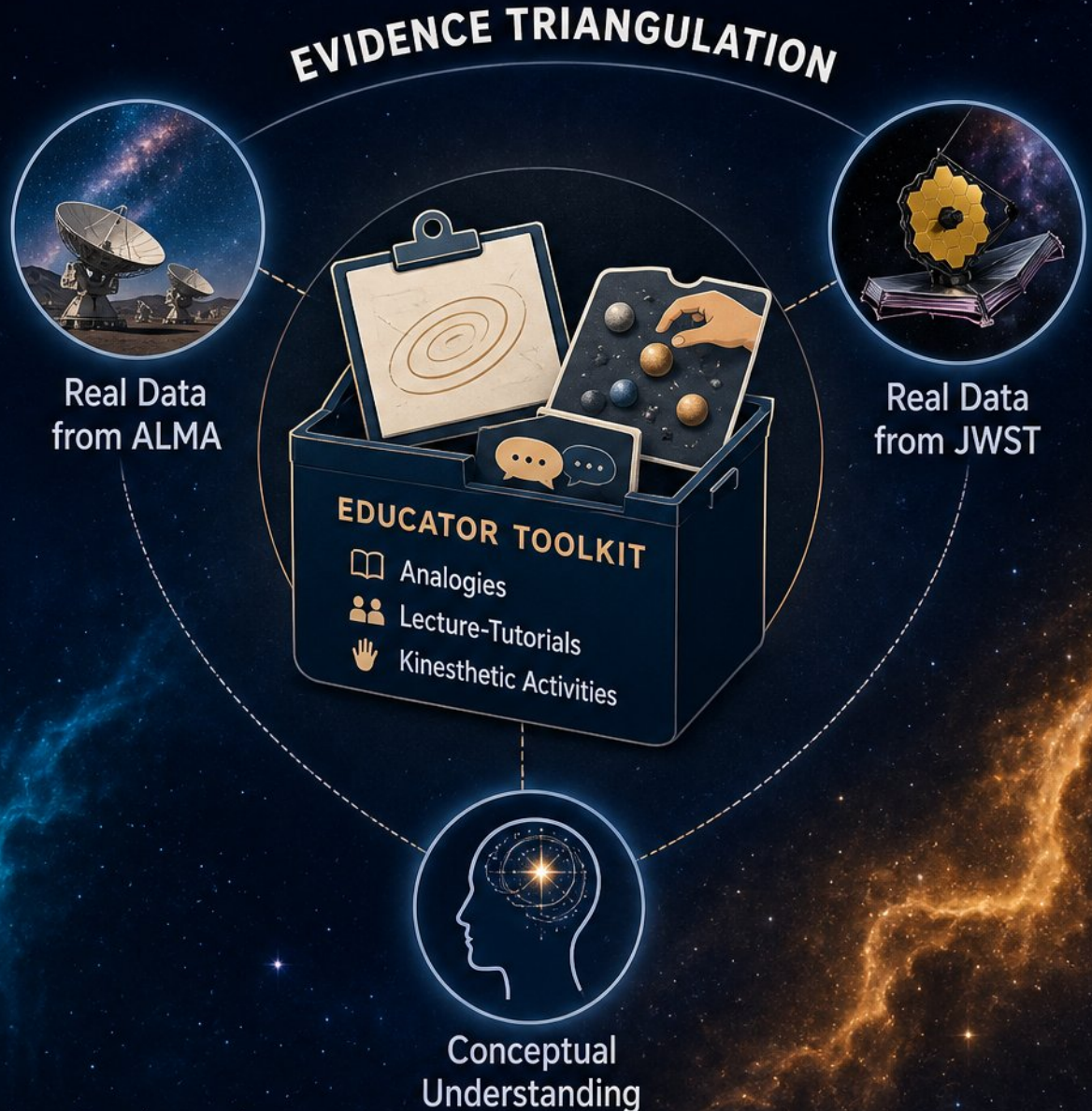
- Replace jargon with plain language for public audiences



- Use concept inventories like the PFCI to measure learning



- Bring in real data from ALMA and JWST



# PersonWise.

PersonWise • AI digital-human course platform



Scan the code or click anywhere to watch this course live, with voice Q&A

[personwise.ai/t/315a89c9/public](https://personwise.ai/t/315a89c9/public)