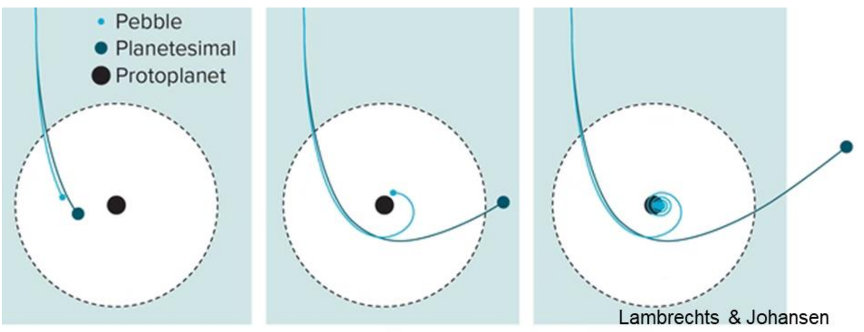
The PPOLs Model
Planetary System Architecture & Composition from Pebble Accretion

Sean McCloat[1], S. Fieber-Beyer[1] & G. Mulders[2]

1 – University of North Dakota, Space Studies; 2 – Universidad Adolfo Ibanez, Santiago Chile

What is pebble accretion?

- Pebble accretion: mechanism for protoplanet growth by collecting inward drifting ~centimeter size solids that coagulate out of dust.
- **"aerodynamically assisted accretion"**: attracted by gravity alone, a planetesimal may scatter instead of accrete. A pebble experiences gravity + gas drag, increasing the collection area for growing protoplanet.



- growth is most efficient for **~km-scale< planetesimals (here called "seeds")**, and overcomes long growth timescales, especially for giant planet cores at distant orbits.
- pebble accretion models typically coagulate pebbles from disk properties, with pebble sizes (Stokes numbers) and flux determined by fragmentation vs drift

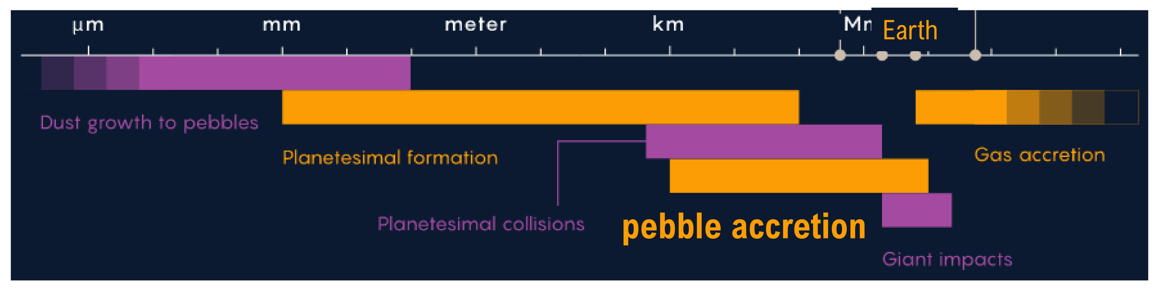


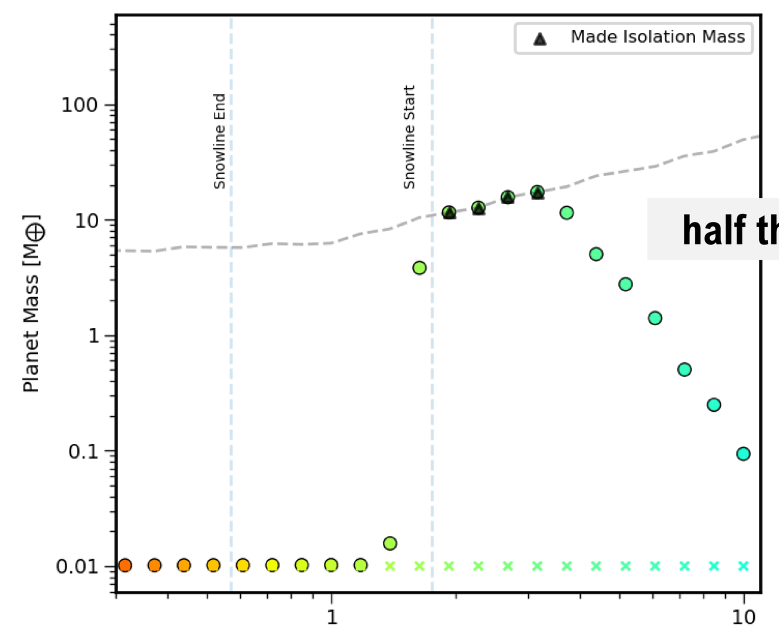
Image: Merrill Sherman/Quanta Magazine

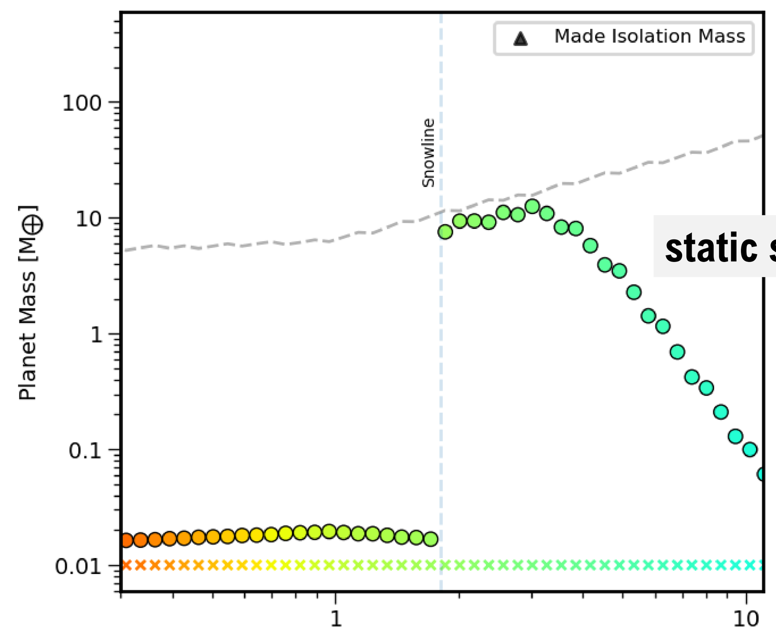
This dissertation uses *pebble-predictor* (Drazkowska et al. 2021) to model pebble formation and *epsilon* accretion recipes (Ormel & Liu 2018) to model accretion efficiency.

- PP yields a single flux-averaged St value, instead of computationally expensive St value distributions.
- We enhance this combination by exploring range of stellar mass, simultaneous growth of any number of seeds, and snow line position and evolution.

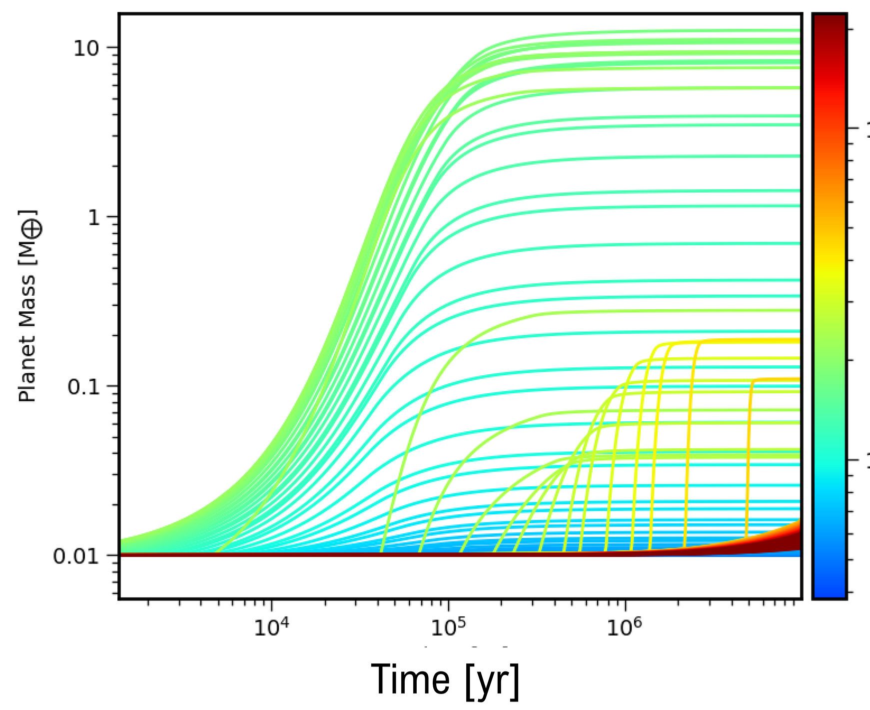
Key PPOLs Mechanisms

- **filtering**: pebbles accreted by an outer seed are removed (*filtered*) from pebble supply inward
- **pebble isolation mass**: protoplanet mass sufficient to create a pressure bump in the gas disk, halting pebble drift. Effectively ends growth of interior seeds.
- **snow line & evolution**: the distance at which conditions allow water vapor to condense into ice/icy pebbles. Location evolves as disk conditions change: here, as solid surface density decreases.

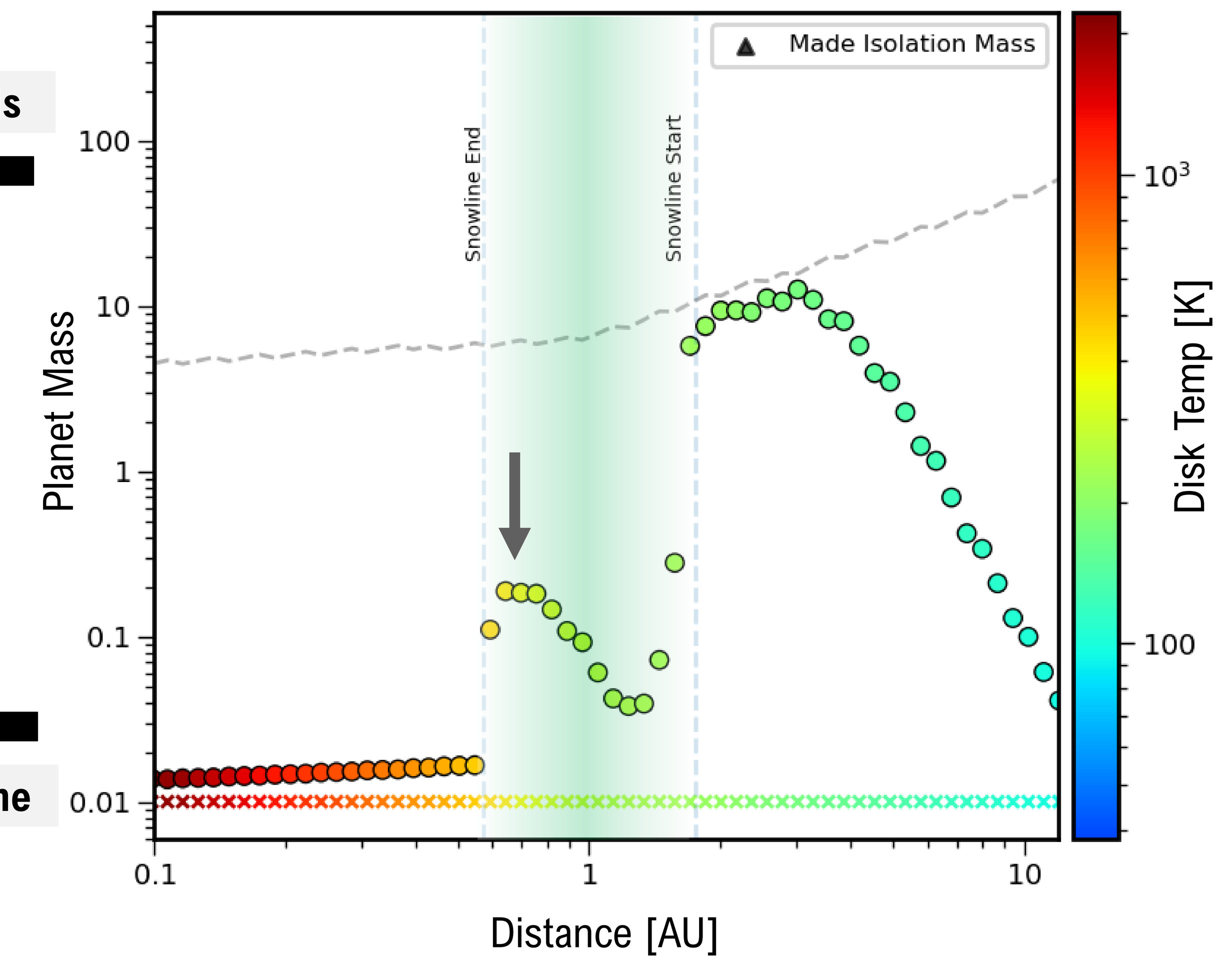




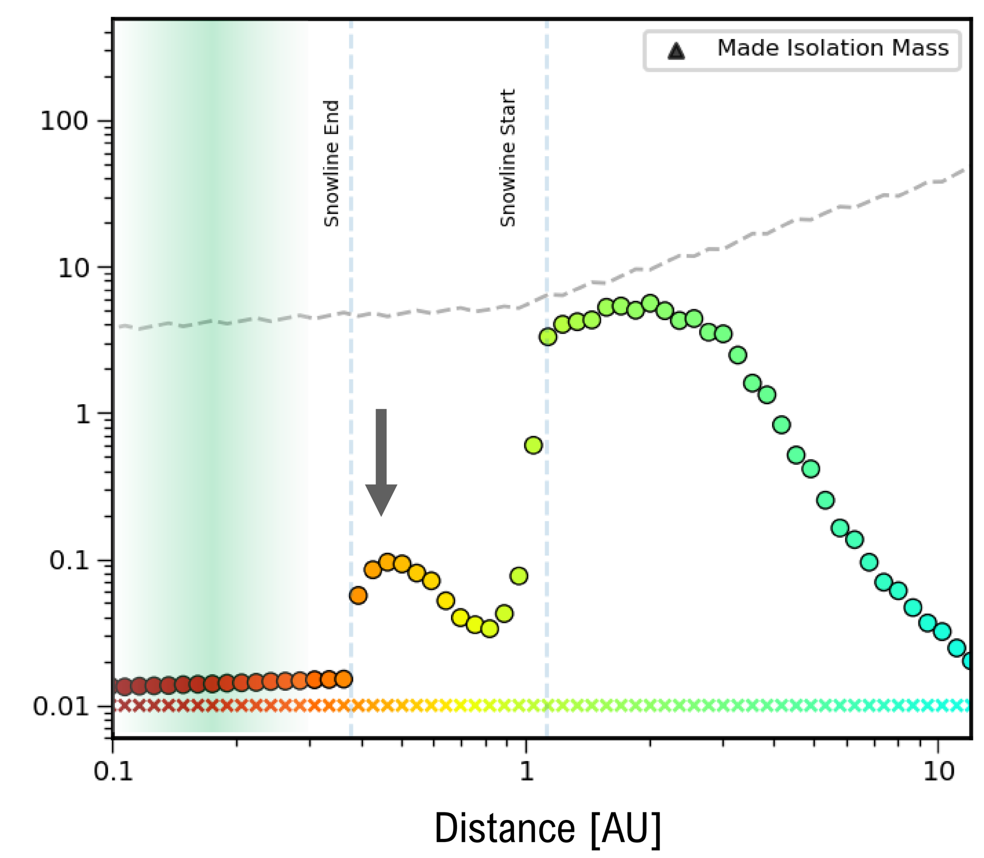
Below: Mass of growing seeds over time. The growth in the last ~million years is driven by the evolving snowline delivering icy pebbles "late" in the disk lifetime.



Protoplanet Mass After Pebble Accretion
1 M_{Sol}



Protoplanet Mass After Pebble Accretion
0.5 M_{Sol}



Snow Line

$r_{ice} \sim \alpha^{(0.61)}\ \Sigma_{g0}{}^{(0.8)}\ f_{DG}{}^{(0.37)}$		snow line position as function of disk parameters, from Savvidou et al. 2020
	inside → outside	
$M_{disk,solids}$	0.5 → 1.0	change in disk solid mass inventory
v_{frag} [cm/s]	1 → 10	fragmentation velocity threshold for coagulating pebbles
ρ_s [g/cm³]	5.5 → 2.5	density of solids, earth-rock to water-rock composition

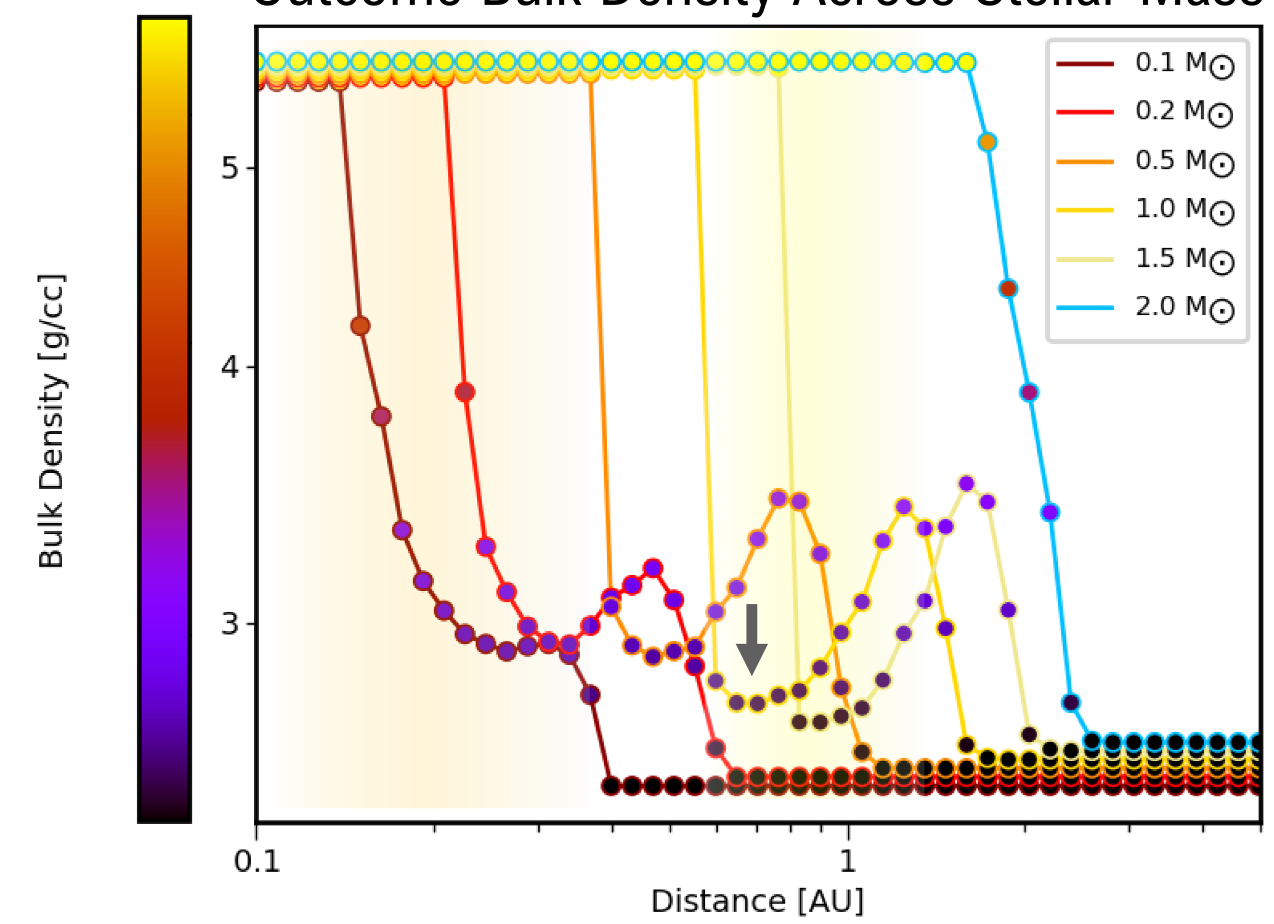
Pebbles Deliver Late Volatiles?

Fewer seeds do not accrete efficiently enough to impact the pebble flux for inner planets, but ~hundreds collectively filter the flux and slow the growth of interior seeds. This prevents a given seed at the snow line from reaching isolation mass and blocking the pebble flux.

When the snow line sweeps inward, the higher dust mass allows icy pebbles to coagulate and accrete – creating the "bump" in planet mass ~0.7 AU for 1 M_{Sol}. Where mass gains are greatest, the bulk density is decreased because of the contribution from icy pebbles.

The combination of ~100 seeds growing simultaneously + snow line evolving inward suggests a pebble-based mechanism for delivering volatiles to planets near the habitable zone of G-, K-, M- stars

Outcome Bulk Density Across Stellar Mass



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