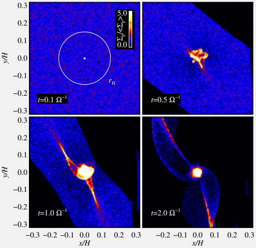
Giant planet formation by pebble accretion

Instabilities and Structures in Proto-Planetary Disks, Marseille
19 September 2012



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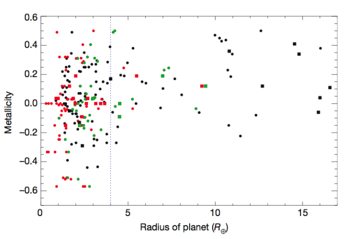
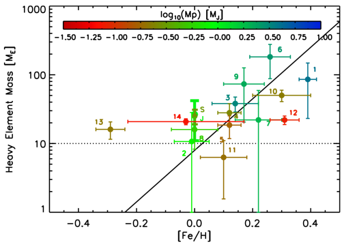
Observational constraints on giant planets

Gas and ice giant planets

- are born in a dusty gas disc
- have a rocky core/ are enriched in metals ($\sim 10\,M_\oplus$)
- form fast ($\lesssim 10^6$ yr)
- and at wide orbital separation ($\gtrsim 10$ AU)



(Buchhave at al, 2012)



(Miller & Fortney, 2011)

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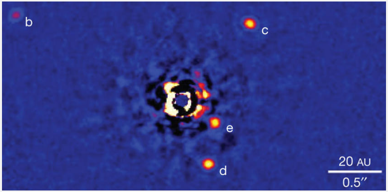

HR8799 planetary system (Marois et al, 2010)

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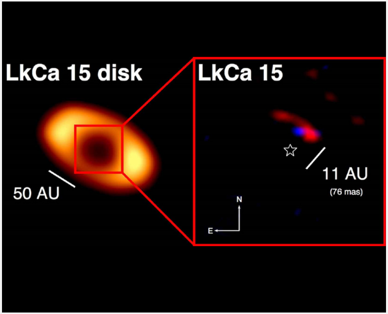


LkCa 15 a: an $\approx$ 1 Myr-old planet (Kraus & Ireland, 2011)

Core accretion scenario

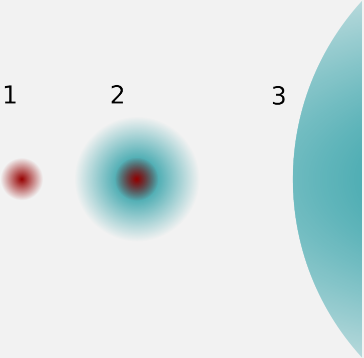
(Pollack et al. , 1996)

1. grow a solid core
2. when $v_{\rm esc} \approx c_{\rm s}$
   slow envelope attraction
   to $M_{\rm env} \approx M_{\rm core} \approx 10 M_{\oplus}$
3. runaway growth of the
   envelope $> 100\ \mathrm{M}_{\oplus}$

within $\tau_{\rm Gas\,disc} \sim 3$ Myr ...

And significant time in 2,3

(Papaloizou & Nelson, 2004)

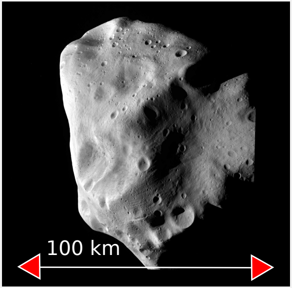


Core formation with planetesimals

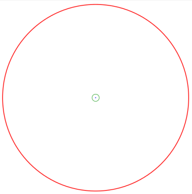
Assume the solid density is in planetesimals…

- planetesimals: size $\sim$ km (Rafikov, 2004 & Dodson-Robinson, 2009)
- planetesimal accretion rate: $\dot{M} \sim \rho \sigma v_\infty$ gravitational focussing ($v_\infty \ll v_{\rm esc}$): $\sigma \sim p R_{\rm H}^2$ with

$$p \sim (R_\odot / r) \sim 10^{-3} (r / 5\,\mathrm{AU})^{-1}$$



Lutetia



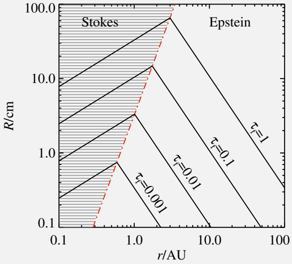
σ vs πr_H^2

Core formation with pebbles

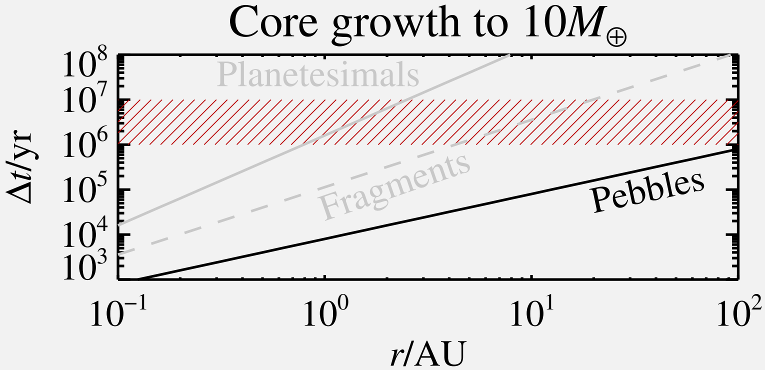
Or assume the solid density is in pebbes...

Pebbles

- Pebbles: size $\sim$ cm $\rightarrow$ feel gas drag
  - *friction time:* $t_\mathrm{f} = v/\dot{v} \propto R/(\rho c_s)$
  - a "natural" size (see also talk by Katrin Ros)

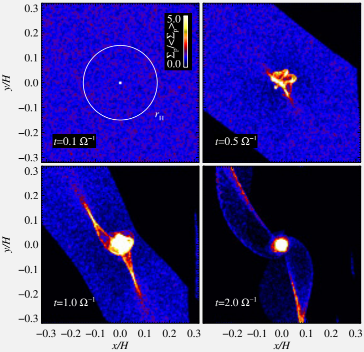


Timescales

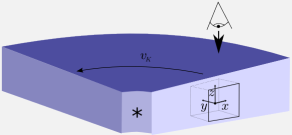


Core growth with planetesimals is slow.

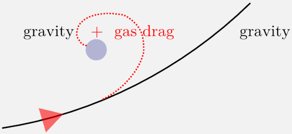
Pebble accretion is fast: Pencil Code results



(Lambrechts & Johansen, 2012)



scatter → capture

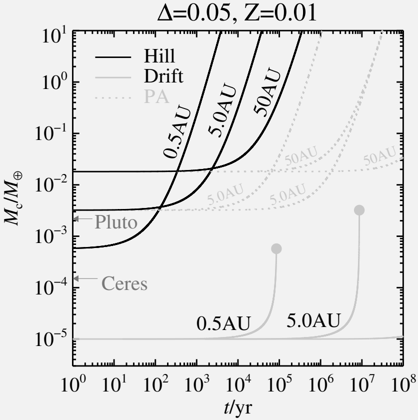


Rapid accretion:

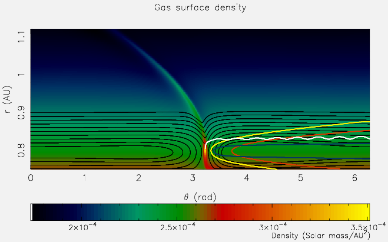
- $\sigma_{\mathrm{pebbles}} \propto \pi R_{\mathrm{H}}^2$
  when $t_{\mathrm{cross}} = \Omega_{\mathrm{K}}^{-1} \approx t_{\mathrm{f}}$
  (true for pebbles)
- 2D accretion $r_{\mathrm{H}} \sim H_{\mathrm{p}}$

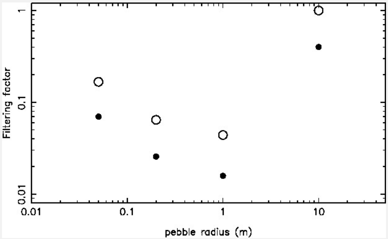
Pebble accretion

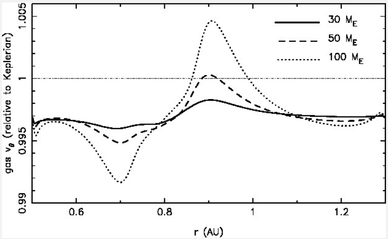
- $\dot{M} \sim 2 r_{\rm H} \Sigma_{\rm p} v_{\rm H} \propto M_{\rm c}^{2/3}$
- resonanant trapping/dust gaps?
  (Weidenschilling & Davis, 1985 / Paardekooper & Mellema, 2004 2006)



Morbidelli & Nesvorny, 2012: large core regime



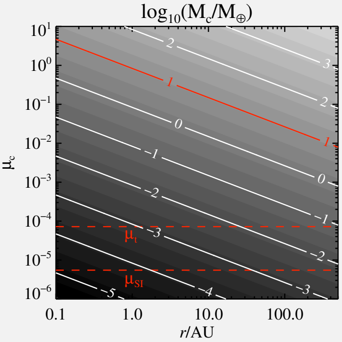


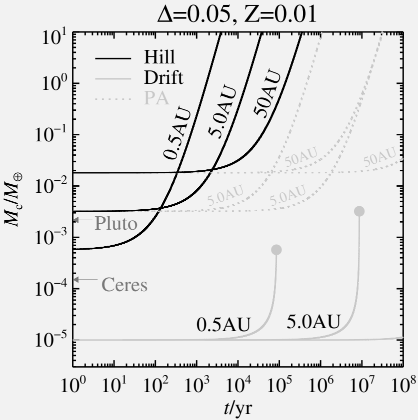


- include gravity large core ($\gtrsim 1\mathrm{M}_\oplus$) on the gas disc
- recover our accretion rates
- filtering factor: accretion/drift ~ 0.1
- accretion shut off when $M \sim 50\,\mathrm{M}_\oplus$

Seed mass necessary

- drift regime when $\Delta v < v_{\mathrm{H}}$
- inefficient growth (core-mass-dependent) up to transition mass





Needed:
pebble clumping+selfgravity
(streaming instability, MRI, BI/RBI → vortices, . . .)
(Johansen, Oishi,. . . 2007, Barge & Sommeria, 1995, . . .)

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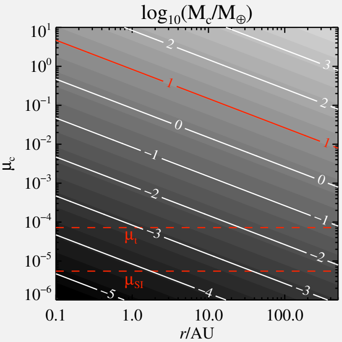

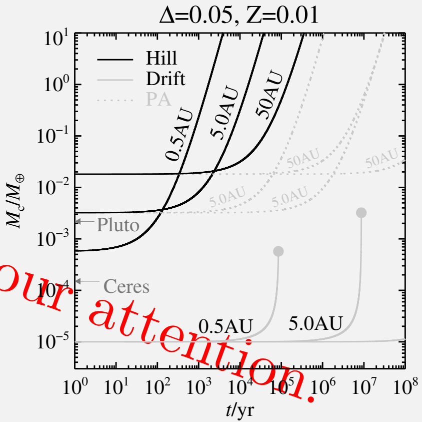

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Thank you for your attention.