Giant planet formation by tiny pebbles

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Theoretical Astrophysics in Lund

How unusual is our solar system? How do black holes form and grow? What powers gamma-ray bursts and supernovae? ...

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Ross Church

Chao-Chin Yang

Serge Nzoke

Alexey Bobrick*

Daniel Carrera*

Kalle Jansson*

Michiel Lambrechts

Katrin Ros *

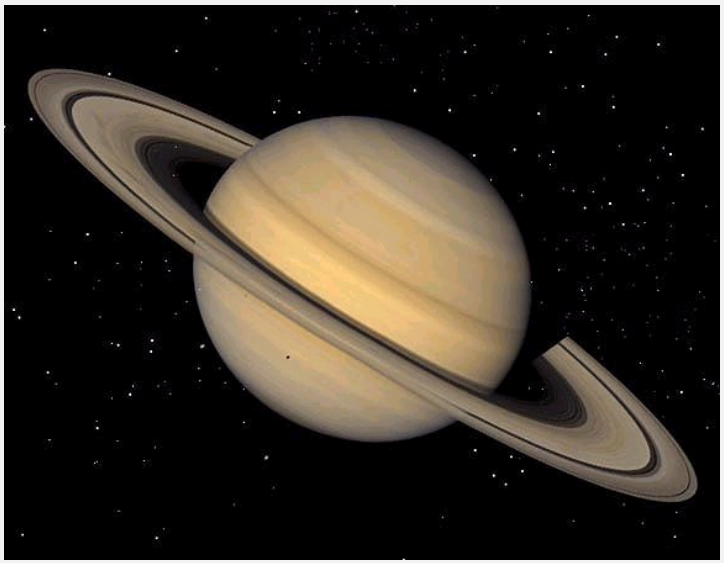
*Check out their posters!

Observational constraints on gas giants

Gas giants:

- exoplanets (`exoplanet.eu`)
- born in a gas disc
- have a rocky core (10 $M_\oplus$)
- like dusty environments
- form fast ($\lesssim 10^6$ yr)
- and at wide orbital separation (> 10 AU)

The protoplanetary disc ≈ 100 AU



Saturn

Observational constraints

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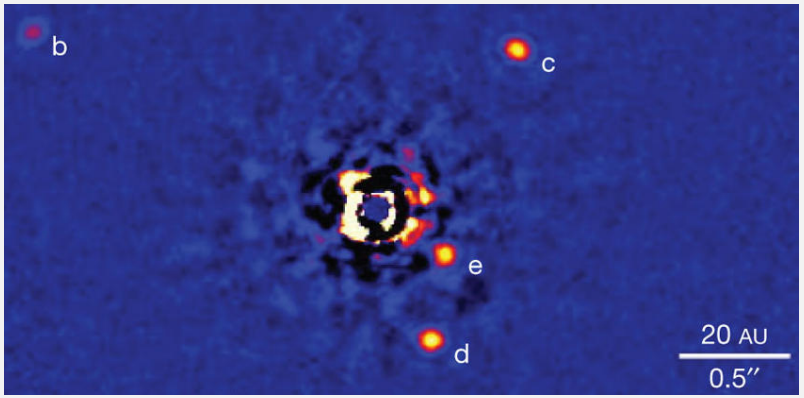

HR8799 planetary system

(Marois et al, 2010)

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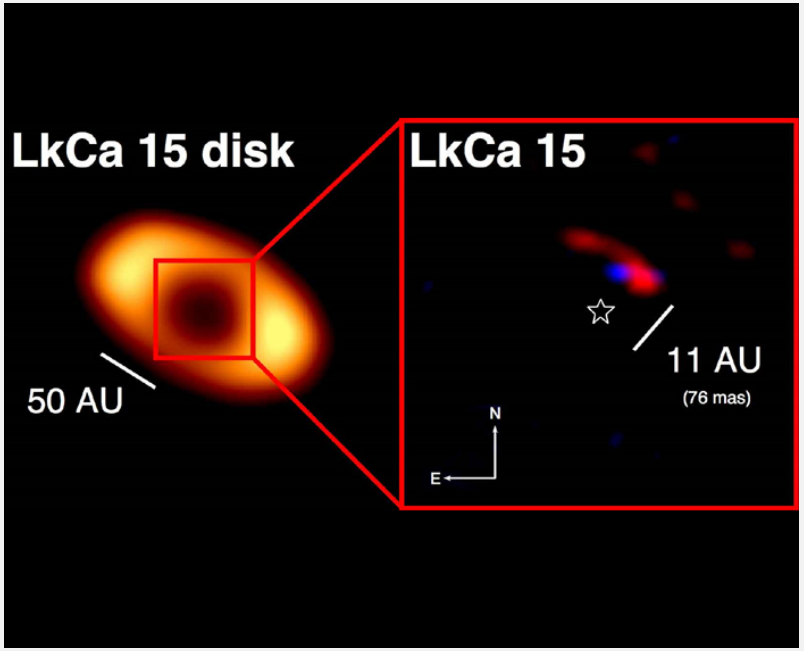


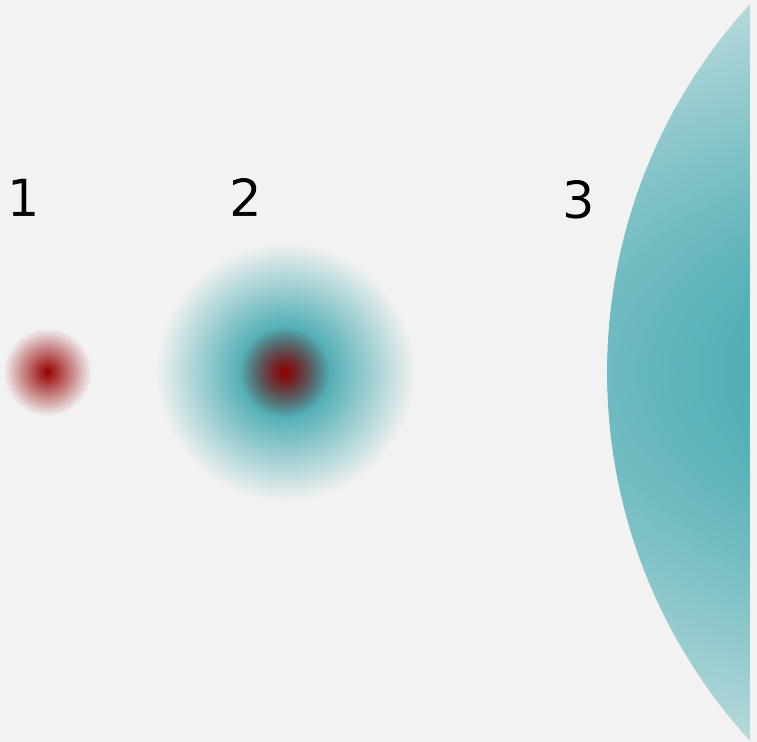
LkCa 15 a: an $\approx$ 1 Myr-old planet (Kraus & Ireland, 2011)

Core accretion scenario

(Pollack et al. , 1996)

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

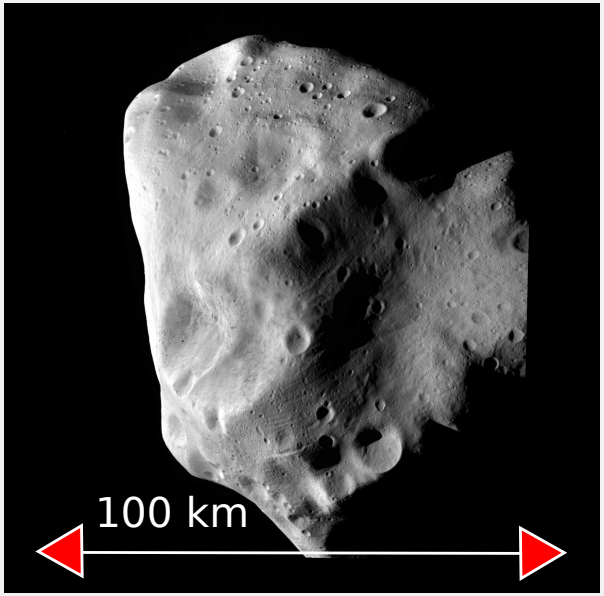
within ≈ 1 Myr ...



Planetesimals and pebbles

The building blocks:

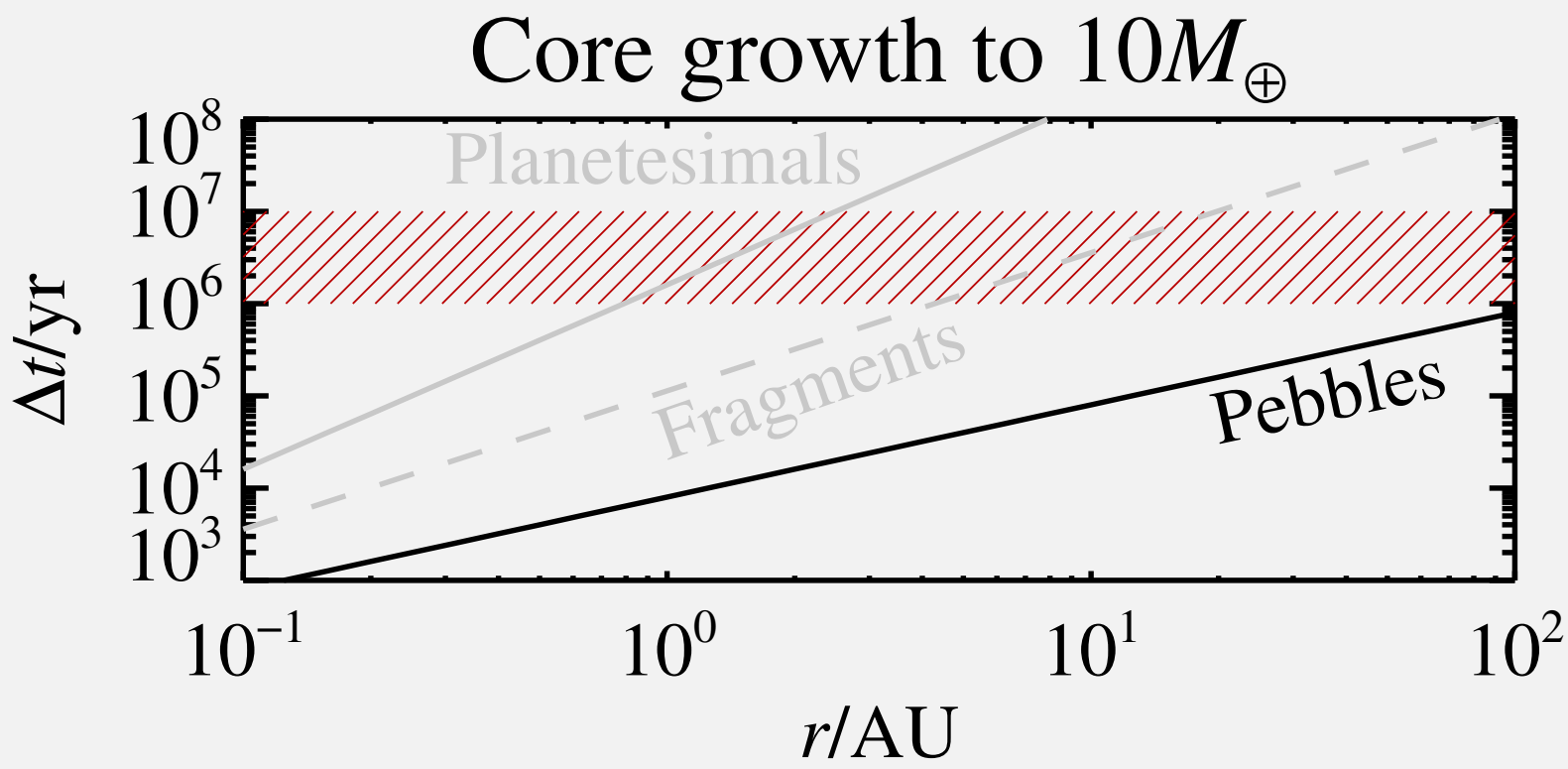
- planetesimals: size $\sim$ km
  (Rafikov, 2004 &
  Dodson-Robinson, 2009)
  OR
- Pebbles: size $\sim$ cm $\rightarrow$
  feel gas drag
  - *friction time:*
    $t_{\mathrm{f}} = v/\dot{v} \propto R$
  - a "natural" size
    (see also poster by
    Katrin Ros)



Lutetia

Pebbles

Timescales

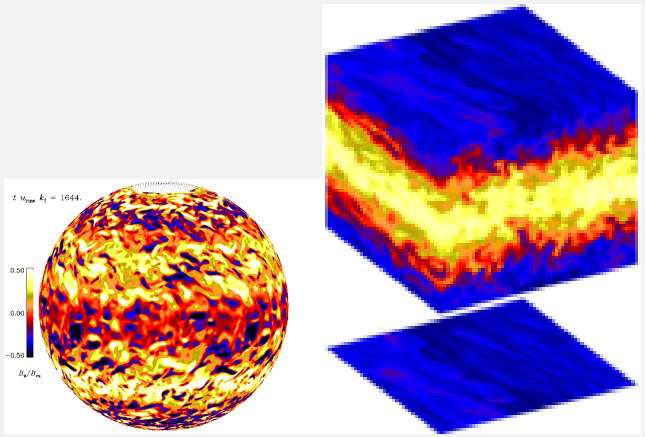


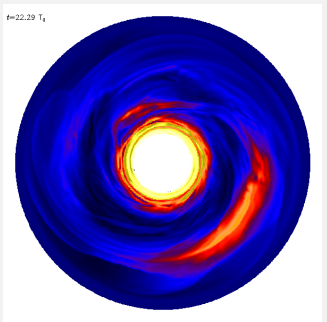
Core growth with planetesimals is slow.

The Pencil Code

- Eulerian grid code
  6th order central finite difference in space

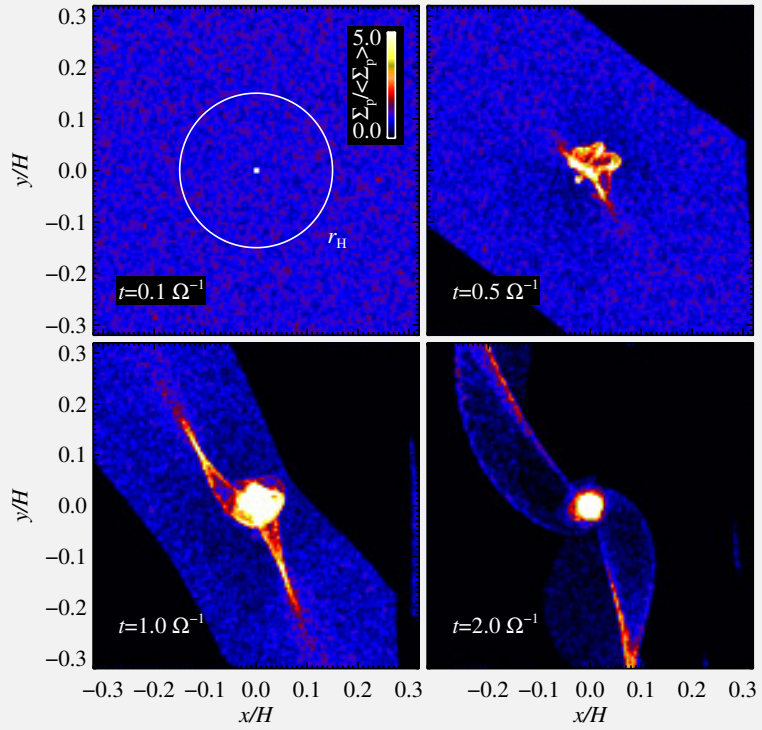
  3rd order Runge-Kutta in time
- Ideal for compressible hydrodynamics (modular general purpose code)



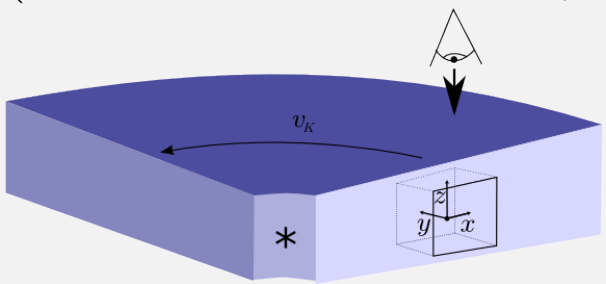


- Code is open source. Check it out at `http://www.nordita.org/pencil-code/`

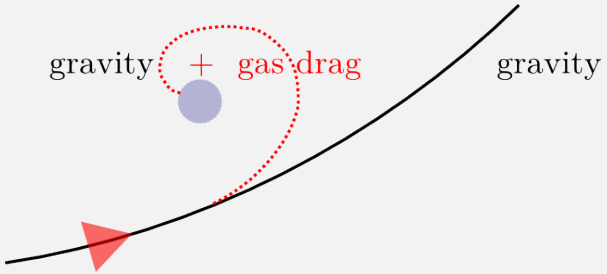
Pebble accretion is fast: Pencil Code results



(Lambrechts & Johansen, 2012)



scatter → capture



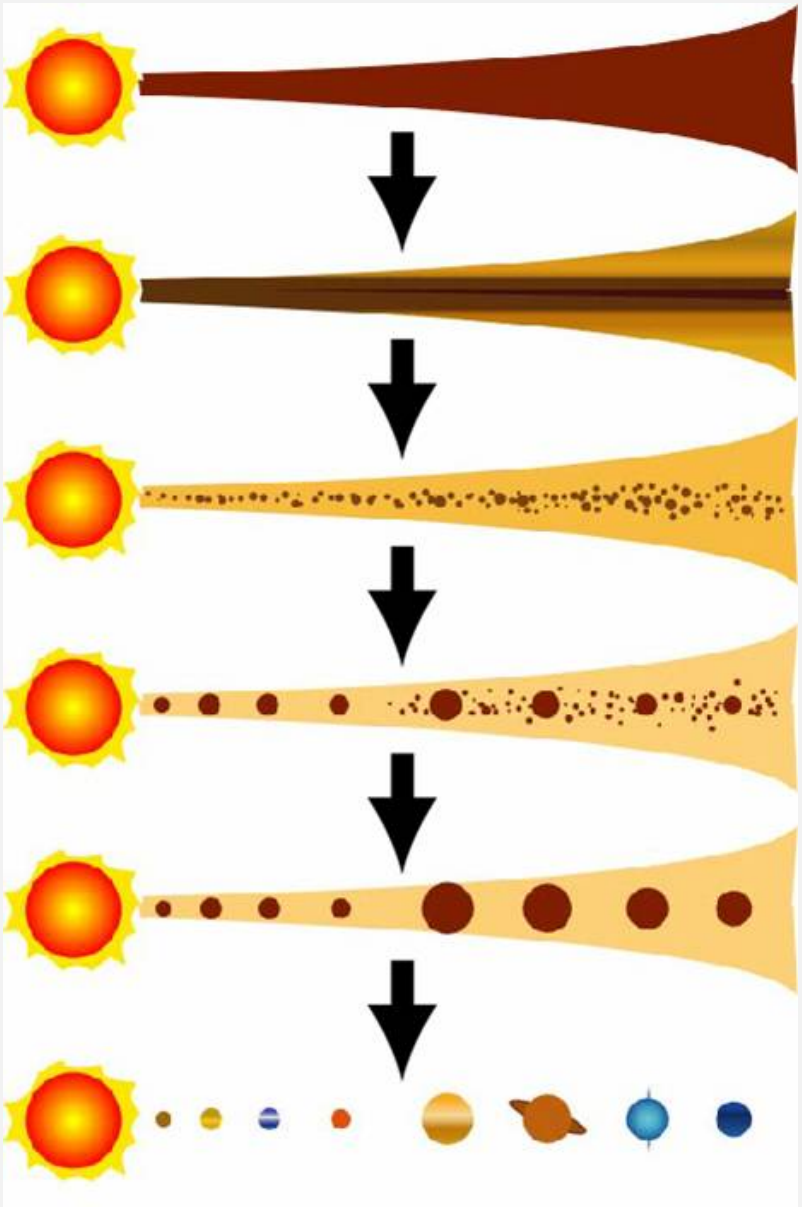
$\dot{M}_{\rm pebbles} \propto R_{\rm H}$ with
$R_{\rm H} \approx 100\times$ capture radius for planetesimals!
(when $t_{\rm g} \approx t_{\rm f}$)

Conclusion: pebble accretion is incredibly rapid.

Planet formation

A time line (?)

- a pebble clumping event
  (Johansen et al, 2007, Nature)
- rapid pebble accretion
- gas giant formed + migrate
- no gas left in disc, only gravity
  Davies M. B., Malmberg D., Church R., Jansson K, Carrera D., ...
- final form of the solar system ...



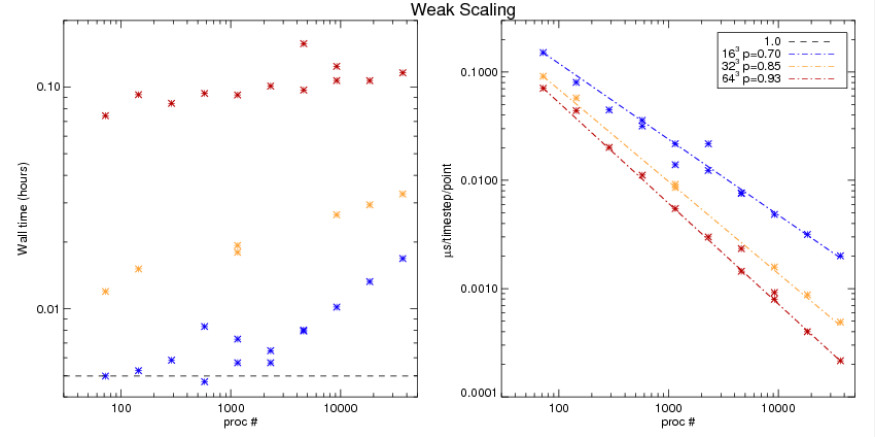
Commercial Break:
Källén seminar for breakthrough discoveries

- organised by
  ATP+Physics PhD
  students
  deadline speaker suggestion:
  07/09/2012
- funding for
  intercontinental flight +
  accommodation
  - 2013-2014 agenda will be at
    `http://www.astro.lu.se/~michiel/kallen`

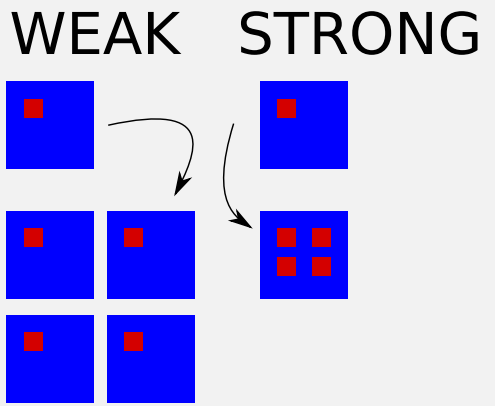
Thank you for your attention.

The Pencil Code: parallelization

- weak scaling on supercomputers



From Wlad Lyra.



Problem size, processor