A possible origin of compact systems of hot Super Earths

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Session 7, Talk : 7.06
Introduction
Principle
Actual Simulation
Parameter space
Conclusion
Questions

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source: exoplanet.eu (May 2nd, 2013)
Compact System of hot super earths

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- N-body simulations: Mercury code (Chambers, 1999)
- 1D disk model (solving energy equation)
  - Density profile \( \propto R^{-d} \)
  - Opacity Table
  - Temperature profile: balance between viscous heating and radiative cooling
- Eccentricity and inclination damping by a gas disk
- Migration from torque formulae (Paardekooper et al., 2011)
Convergence Zone

Outward Migration

Inward Migration

Semi Major Axis (AU)

0 1 2 3 4 5 6 7 8

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BUT...
Lindblad: typically Inward Migration

Corotation torque: Inward/Outward Migration

Total Torque = Lindblad Torque + Corotation Torque
(Bitsch & Kley, 2010) 
poster by S. Fendyke (4.22)

Corotation torque modified by eccentricity

- $e=0$
- $2\times_s$
- $e>0$
Eccentricity? In disk?
(Cossou et al., 2013) A&A, 553, L2

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Convergence Zone

\( e = x_s \)

1 planet

2 planets

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Migration map

Planet mass ($m_{\text{earth}}$)

Semi-major axis (AU)

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Migration map

Semi-major axis (AU)

Planet mass (m_{earth})

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Migration map

Semi-major axis (AU)

Planet mass (m_{earth})

Outward

Inward

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Migration map

Semi-major axis (AU)

Planet mass (m_{earth})

Outward

Inward

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Presence of Resonances
High sensitivity to migration map

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Presence of Resonances

High sensitivity to migration map
Disk parameters : Density
\[ \Sigma(R) = 1500.0 \times R^{-\frac{1}{2}} \text{g/cm}^2 \]

Evolution of the total torque \( \Gamma_{\text{tot}}/\Gamma_0 \)

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\[ \Sigma(R) = 0800.0 \times R^{-1/2} \text{ g/cm}^2 \]

Evolution of the total torque \( \Gamma_{\text{tot}}/\Gamma_0 \)
\[ \Sigma(R) = 0.300 \times R^{-1/2} \text{ g/cm}^2 \]

Evolution of the total torque \( \Gamma_{\text{tot}}/\Gamma_0 \)

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Compact Systems of Hot Super Earths

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Compact Systems of Hot Super Earths

Jupiter candidates also
Compact Systems of Hot Super Earths

Jupiter candidates also

Disk parameters
- Turbulence
- Photo-evaporation
- Gas accretion
- Volatile content

1. Compact Systems of Hot Super Earths
2. Jupiter candidates also
3. Disk parameters
4. Ongoing...
Take home message

Multiple planets do NOT converge at Convergence Zone!

Christophe COSSOU christophe.cossou@u-bordeaux1.fr (post-doc ?)
b/h = 0.6
adiabatic index = 1.40
mean molecular weight = 2.35
viscosity type = alpha (Alpha-prescription, with constant alpha)
alpha = 5 \cdot 10^{-3}
opACITY type = hure (Opacity table from (Hure, 2000))

disk : R \in [0.1; 100] \text{AU}
initial surface density = 300 \cdot R^{-1/2} \text{g/cm}^2
inner smoothing width = 0.005 \text{AU}

include turbulence = False
include irradiation = True
Stellar surface temperature = 5700 \text{K}
Stellar radius = 4.65 \cdot 10^{-3} \text{AU}
Disk Albedo = 0.5
Opacity

- (Bell & Lin, 1994)
- (Zhu & Hartmann, 2008)
- (Huré, 2000) (opacity table)
opacity laws (Bell & Lin, 1994)

Evolution of the total torque $\Gamma_{\text{tot}}/\Gamma_0$
opacity laws (Zhu & Hartmann, 2008)

Evolution of the total torque $\Gamma_{\text{tot}}/\Gamma_0$
opacity table (Huré, 2000)

Evolution of the total torque $\Gamma_{\text{tot}}/\Gamma_0$
Temperature profile

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eccentricity damping
inclination damping