The Formation and Retention of Gas Giants around Stars with Different Metallicities

**Shigeru Ida** (Tokyo Inst. of Tech.)

collaborator: Doug Lin (UCO/Lick)

  - core accretion from planetesimals, gas accretion, gap formation, type-II migration
  - predict deficit of planets of 10-100 $M_{\oplus}$ inside 3AU
- metallicity dependence *Ida & Lin (submitted)*
  - predict that $P$ increases with metallicity

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**Motivation**

observation of extrasolar planets:
metallicity dependence *(Fischer & Valenti)*

(1) pollution by infall of planets?
(2) high formation efficiency in metal-rich disks?

We consider the possibility of (2) with a theoretical model based on core accretion scenario.
Model

- core accretion from planetesimals
  - rate: two-body approx. (Safronov 1969)
  - isolation: oligarchic growth (Kokubo & Ida 1998)
    - giant impacts after gas depletion are also included (Kominami & Ida 2000)
- gas accretion
  - critical core mass $M_{\text{crit}} = 10 \left( \frac{dM_{\text{core}}/dt}{10^{-6} M_\odot / \text{yr}} \right)^{1/4} M_\odot$
  - KH contraction $t_{\text{KH}} \approx 10^9 \left( \frac{M}{M_\odot} \right)^{-3} \text{yr}$ (Pollack et al. 1996, Ikoma et al. 2000)
- type-II migration
  - start: planetary torque > viscous torque
  - rate: $\tau_{\text{mig}} = 10^6 f_{\text{gas}}^{-1} \left( \frac{M}{M_\odot} \right) \left( \frac{a}{1 \text{AU}} \right)^{1/2} \text{yr}$
  - halt: $a = 0.04 \text{AU}$ (Lin & Papaloizou 1985, 1993)
- termination
  - Hill radius $> 1.5 \times$ disk scale height
  - disk gas depletion

Monte Carlo simulation: initial conditions

- surface density distribution
  - gas $\Sigma_{\text{gas}} = f_{\text{gas},0} e^{-a / \tau_{\text{dep}}} \times 2400 \left( a / \text{AU} \right)^{-1.5} \text{g/cm}^2$
  - dust $\Sigma_{\text{dust}} = f_{\text{dust}} f_{\text{ice}} \times 10 \left( a / \text{AU} \right)^{-1.5} \text{g/cm}^2$

- $f_{\text{dust}} = f_{\text{gas},0} = 1$: min. mass solar nebula
- observations: $M_{\text{disk}} = (0.1-30) M_{\odot}$ solar nebula
- log10$f_{\text{gas}}$ - distribution: $\propto \exp(-x-0.25^2)$
- log10$f_{\text{dust}}$ - distribution: $\propto \exp(-x-0.25^2) (Z_{\odot} - Z_{\star})$
  - $Z_{\star}$: metallicity [Fe/H] of a host star

- $a$ - distribution: uniform in log scale
- disk lifetime: $\tau_{\text{dep}} = 10^6 - 10^7 \text{yr}$
- stellar mass: $M_{\star} = 0.7 - 1.4 M_\odot \rightarrow a_{\text{ice}} = 2.7 (M_{\star}/M_\odot)^2$
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Results: $\Delta Z = Z_* - Z_\odot = 0$

![Diagram showing the formation of different types of planets as a function of semimajor axis and planet mass.]

Formation of “Planet Desert”

![Diagram illustrating the formation of gas giants and terrestrial planets, showing the deficit of intermediate mass planets in the planet desert.]

Dr. Shigeru Ida, Tokyo Institute of Technology (KITP Planet Formation 2/24/04)
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**Results:**

$\Delta Z - \text{dep.}$

$M_{\text{core}} \propto f_{\text{dust}}^{3/2}$

Kokubo & Ida 1998
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**Results:**

\[ \Delta Z - \text{dependence} \]

- \( \tau_{\text{dep}} = 10^5 - 10^6 \) y
- \( \tau_{\text{dep}} = 10^6 - 10^7 \) y
- \( \tau_{\text{dep}} = 10^4 - 10^5 \) y

- *absolute values change with \( \alpha \)*

**core accretion model reproduces the dependence**

⇔ self-grav. instability model

**Summary**

- We constructed a deterministic planet formation model
  - core accretion from planetesimals, gas accretion,
    gap formation, type-II migration

- predictions [consistent with observations]
  - deficit of planets of 10-100\( M_\oplus \) at \( a < 3\) AU (Planet Desert)
  - \( P \) increases with metallicity

- future issues
  - jumping jupiter
  - type-I migration
    (random-walk type is already included)
  - effects near disk inner edge
    - truncation