Formation of The Jovian and Saturnian Satellite Systems

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Jovian System v.s. Saturnian System

rocky | rocky | icy | icy, undiff.
---|---|---|---
Io | Europa | Ganymede | Callisto

mutual mean motion resonances (MMR)

only one big body

icy, undiff.

Titan
Circum-planetary disk models

Actively-Supplied Accretion Disk
[Canup & Ward, 2002]

- M_{satellites}/M_{planet} \sim 10^{-4}
  [Canup & Ward, 2006]

- Difference b/w Jovian and Saturnian satellite systems
  [Sasaki et al., 2010; Oghihara et al., 2012]

“Minimum Mass” Disk
[Mosqueira & Estrada, 2003]

- Only for Jovian system
- Unrealistic initial conditions
  [Tanigawa et al., 2012 JpGU]
- Difficult to make satellites(?)
  [Miguel, Sasaki & Ida, in prep.];
Circum-planetary disk models

**Actively-Supplied Accretion Disk**
[Canup & Ward, 2002]

- Inflow (gas + small solids)
- $v = \alpha cH$
- $r_d > r_o$
- $H \sim c/\Omega$
- $M_{\text{satellites}}/M_{\text{planet}} \sim 10^{-4}$
  [Canup & Ward, 2006]
- Difference b/w Jovian and Saturnian satellite systems
  [Sasaki et al., 2010; Oghihara et al., 2012]

**“Minimum Mass” Disk**
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Actively-Supplied Accretion Disk

Uniform mass infall $F_{\text{in}}$ from the circum-stellar disk
Infall regions: $r_{\text{in}} < r < r_c$ ($r_c \sim 30R_p$)
Diffuse out at outer edge: $r_d \sim 150R_p$
Infall rate decays exponentially with time
Temperature: balance of viscous heating and blackbody radiation
Viscosity: $\alpha$ model

\[ \nu = \alpha c H \]

![Diagram of inflow (gas + small solids)]
Overview of Sasaki et al. (2010)

**Circum-Planetary Disk**
  - Satellites formed in c.-p. disk
  - Actively-supplied accretion disk
  - Supplied from circum-stellar disk
  → Analytical solution for $T, \Sigma$

**Satellite Formation**
  - Analytical solution for accretion timescale
  - Type I migration timescale
  - Trapping condition in MMR

**Adding New Ideas**

**Disk boundary conditions**

*Difference of Jovian/Saturnian systems is naturally reproduced.*
The New Ideas

**Jupiter**
- inner cavity
- opened up gap in c.-s. disk
  - infall to c.-p. disk stop abruptly

**Saturn**
- no cavity
- did not open up gap in c.-s. disk
  - c.-p. disk decay with c.-s. disk

Difference of “inner cavity” is from Königl (1991) and Stevenson (1974)
Difference of gap conditions is from Ida & Lin (2004)
Because the infall mass flux per unit area is constant, the total mass flux to satellite feeding zones is larger in outer regions.
Type I migration is halted near the inner edge.

The outer most satellite migrates and sweeps up the inner small satellites.
Proto-satellites grow & migrate repeatedly
They are trapped in MMR with the innermost satellite
Jovian System

Total mass of the trapped satellites > Disk mass
→ the halting mechanism is not effective
→ innermost satellite is released to the host planet
Jovian System

after the gap opening → c.-p. disk deplete quickly
Saturnian System

No inner cavity

outer proto-satellite grow faster & migrate earlier
Large proto-satellites migrate from the outer regions and fall to the host planet with inner smaller satellites.
Saturnian System

c.-p. disk depleted slowly with the decay of c.-s. disk
Monte Carlo Simulation (n=100)

Parameters:

- Disk viscosity (α model) \( \alpha = 10^{-3} - 10^{-2} \)
- Disk decay timescale \( \tau_{in} = 3 \times 10^6 - 5 \times 10^6 \text{ yr} \)
- Number of “satellite seeds” \( N = 10 - 20 \)
Results: Distribution of the number of large satellites

- Total count of the case:
  - Jovian:
    - 1: 0
    - 2: 0
    - 3: 0
    - 4: 1
    - 5: 1
    - 6: 0
    - 7: 0
  - Saturnian:
    - 0: 1
    - 1: 2
    - 2: 0
    - 3: 4
    - 4: 3

Bar charts show the distribution:
- Jovian: The number of large satellites from 0 to 7.
- Saturnian: The number of large satellites from 0 to 4.
Results: Distribution of the number of large satellites

inner two bodies: rocky & outer two bodies: icy

icy satellite & large enough (~$M_{\text{Titan}}$)
Results: Properties of produced satellite systems

- Saturnian
- Titan

- Jovian
  - rocky component
  - icy component

Galilean Satellites

- $10^{-6}$
- $10^{-5}$
- $10^{-4}$
- $10^{-3}$

Saturnian

- Titan

- $10^{-6}$
- $10^{-5}$
- $10^{-4}$
- $10^{-3}$

$a/R_p$
Results: Properties of produced satellite systems

Saturnian

Titan

Jovian

Galilean Satellites

rocky component

icy component

inner three bodies are trapped in MMR

the largest satellite has \sim 90\% of total satellite mass

\begin{align*}
M_p & \approx 1e-6 \quad a/R_p \\
1e-3 & \quad 1e-4 \\
1e-5 & \quad 1e-6
\end{align*}
Summary

- **Jovian Satellite System v.s. Saturnian Satellite System**
  Difference of size, number, location, and compositions

- **Satellite Accretion/Migration in Circum-Planetary Disk**

- **The Ideas of Disk Boundary Conditions**
  Difference of inner cavity opening and gap opening conditions

- **Monte Carlo Simulations**
  Difference of Jovian/Saturnian system are naturally reproduced