Disk Instability vs. Core Accretion: Observable Discriminants

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Motivation

- Disk Instability vs. Core Accretion
- Formed planet : forming planet :: smoking gun : caught in the act
- Most simulations of disk-planet interactions start with fully-formed planet
- Push high-contrast imaging to the limit
Scattered Light

\[ \tau = \frac{2}{3} \]

To observer

Flared disk

Isotropic Scattering

\[ F = F_{\text{inc}} \cos \theta = \mu \frac{F_*}{r^2} \]

\[ F_{\text{inc}} = \frac{F_*}{r^2} \]

\[ \theta \]
Disk Instability

- 3D hydrodynamic simulations of disk instability by Boss 2001
- Self-gravitating clump formed

Jang-Condell & Boss 2007
J-C & Boss 2007

<table>
<thead>
<tr>
<th>Distance</th>
<th>0.01&quot; (30m)</th>
<th>0.04&quot; (8m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>335 yr</td>
<td></td>
<td></td>
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<tr>
<td>339 yr</td>
<td></td>
<td></td>
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<tr>
<td>346 yr</td>
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Distance = 140 pc

June 3, 2007
Features of Disk Instability

- Scattered light probes upper layers of disk
- Filamentary structures
- Variability over several years’ time
- Need at least 0.01" resolution (GMT, TMT; ALMA)

Core Accretion

- Planet cores embedded in gaseous disks
- 10-20 Earth masses (0.03-0.06 Jupiter masses)
- Assume hydrostatic equilibrium, steady state
Planet Shadows

shadowing brightening

Jang-Condell & Sasselov 2003, 2004

Scattered Light

10 M_E  20 M_E  50 M_E

4 AU  8 AU

Jang-Condell, in prep
Features of Core Accretion

- Smooth overall disk
- Paired shadow/brightening at planet position
- $10^{-9} - 10^{-8}$ contrast ratio (surface brightness)
- Need <0.01” resolution

Comparison

<table>
<thead>
<tr>
<th>Disk Instability</th>
<th>Core Accretion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early YSO (Class I)</td>
<td>Later YSO (Class II)</td>
</tr>
<tr>
<td>~$10^{-5}$ M$_{\text{sun}}$/yr</td>
<td>~$10^{-7}$ M$_{\text{sun}}$/yr</td>
</tr>
<tr>
<td>Massive disk ~0.1 M$_{\text{sun}}$</td>
<td>Small disk ~0.01 M$_{\text{sun}}$</td>
</tr>
<tr>
<td>Turbulent structure, highly variable</td>
<td>Quiescent, stable structure</td>
</tr>
<tr>
<td>Planet location indeterminate</td>
<td>Feature at planet position</td>
</tr>
<tr>
<td></td>
<td>Very high angular resolution &lt;0.01”</td>
</tr>
<tr>
<td></td>
<td>Very high contrast &lt;$10^{-8}$</td>
</tr>
</tbody>
</table>
Future Work

- Inclined disks
- Thermal emission, ALMA wavelengths
- Shadowing and illumination on partial gaps
- Include hydrodynamics in core accretion scenario

Partial Gaps

- Partial clearing of a gap by sub-Jupiter-mass planets
- Subject to shadowing and illumination, just as dimples
- Larger feature, more easily observed

Bate, et al. 2003

30 M_E
10 M_E
3 M_E
1 M_E
1 M_J
1/3 M_J
Observational Challenges

- Angular resolution <0.01"
- High contrast imaging <10^{-7}
- Small inner working angle <0.05"
- High sensitivity

Thermal Emission

<table>
<thead>
<tr>
<th>$10 , M_\oplus$</th>
<th>$20 , M_\oplus$</th>
<th>$50 , M_\oplus$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 AU 40 µm</td>
<td>8 AU 70 µm</td>
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</table>

Jang-Condell, in prep