Disks, accretion and ejection in BD/VLM stars

Antonella Natta

Arcetri & DIAS
BDs/VLMS have disks, accrete and eject matter
Why is it interesting?

- Relevance for formation mechanism: same as stars?
- And for disk physics (large leverage)
- Can BDs form planets?
First detections of dusty disks from near&mid-IR excess

✓ Ground-based & ISO

Comeron et al. 1999, 2000
Natta & Testi 2001
Natta et al. 2002
Spitzer

✓ Large samples (statistics)
✓ SEDs up to mid-IR
  – Complete to ~20-30 $M_J$ (nearby star-forming regions)
  – Fraction of disks similar to TTS

No disk masses
No disk radii ($R>10$ AU)
Herschel

- ~ 50 BDs:
  - 80% detected at 70 mic
  - 30% detected at 160 mic
- Masses: very low
- No need for settling

P. Harvey: GTO program (Poster #21)
Sub-mm (Scuba-2)

- 7 new objects (3 in Taurus and 4 in TWA) with SCUBA-2 (850mic)
- Detections: 2 in Taurus, 0 in TWA
- Disk masses of BDs: \( \frac{M_d}{M_*} \ll 0.1 \)
- \( M_{\text{disk}} < 1 \, M_J \)

Mohanty et al. 2011 (talk)
Low disk masses

✓ No Jupiter-mass planets
✓ Earths?
✓ Planetesimals?
Grain evolution

- From SEDs: evidence of sedimentation, faster than in TTS

Szucs et al. 2010: both low-mass (G5-M4.5) and VLMOs (M4.75-M9.5) need grain sedimentation, VLMOs more so than low-mass stars.
Silicates

- 10 mic silicates more evolved than in TTS

Pascucci et al. 2009, see also Poster #37 by Oliveira
Pebbles in BD disks?

- Evidence of mm-size grains in the outer disks of TTS: impossible!

- Grain growth is controlled by gas-dust coupling (gas density and motions)
  - Coalescence
  - Fragmentation
  - Radial drift

- Model predictions for low-mass disks in BD: no growth!

- 2MASS 0444+2512: detected at 450, 850, 1.3mm, 3.47mm (see Sholz et al. 2006, Bouy et al. 2008, Mohanty et al. 2011): shallow (sub)-mm spectrum

4 BDs with ALMA Early Science

Ricci et al., 2010, 2011 etc. (ESO), see poster #43 and talk by Testi
Birnstiel et al. 2010, 2011 etc., Pinilla et al. 2011 (Heidelberg)
If BD disks have mm-size grains (as TTS disks), this is an indication that they can form planetesimals & earths.

We do not understand how
Accretion

✓ Many young BDs have evidence of accretion
✓ Macc in BDs is lower than in more massive stars: $M_{\text{acc}} \propto M_{\text{star}}^2$
✓ Macc decreases on average with time also for BDs
✓ The fraction of accreting BDs is lower in older star forming regions
✓ There are BDs with (relatively) high accretion rates; some very old?

Statistics has improved, but most Macc derived from Halpha
X-Shooter spectra

- Echelle spectrometer on UT2/ESO
- Resolution 4000-9000 (75-33 km/s)
- Good sensitivity
- Simultaneous coverage from 300-2400nm (U-K)

J053825.4-024241 (SO 500): L=0.03 Lsun, M=0.06 Msun, D=360 pc

U~21mag

Talk by Alcala’, Poster #46 (Stelzer), #44 (Rudolf)
Direct measurement of Lacc

Template (Class III) + BC from slab model
Accretion luminosity

<table>
<thead>
<tr>
<th>Lacc</th>
<th>0.1</th>
<th>1e-4</th>
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<tbody>
<tr>
<td>$H\alpha$</td>
<td>3%</td>
<td>10%</td>
</tr>
<tr>
<td>H9</td>
<td>0.2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Pa$\beta$</td>
<td>0.2%</td>
<td>1%</td>
</tr>
<tr>
<td>Br$\gamma$</td>
<td>0.05%</td>
<td>0.02%</td>
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<tr>
<td>CaII$_{8542}$</td>
<td>0.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>HeI$_{5876}$</td>
<td>0.05%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Uexc</td>
<td>15%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Empirical correlations

Continuum excess emission
Hydrogen lines
He lines
CaII lines
Xshooter sample: few tens TTS, ~10 BDs

✓ Improved estimates of secondary accretion indicators into BD regimes

1: Halpha
2: Hbeta
3: Hgamma
4: H9
5: Pa_gamma
6: Pa_beta
7: HeI
8: NaI
9: CaII854nm
10: CaII866 nm
11: Uband

Rigliaco et al. 2010 and in prep.
Physical conditions of the emitting gas

Hydrogen slab model

- Electron density
- Temperature
- Velocity field
- Slab depth
- Level population
- Area

We need predictions of line intensities
BDs have jets: spectroastrometry in forbidden optical lines

<table>
<thead>
<tr>
<th>Object</th>
<th>Spectral Type</th>
<th>Estimated Mass (M\textsubscript{jup})</th>
<th>Lines analysed with spectro-astrometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO-Cha1 217</td>
<td>M6.2</td>
<td>80\textsuperscript{1}</td>
<td>[SII] λ6716, 6731; [OI] λ6300, 6363</td>
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<tr>
<td>2MASS1207-3932</td>
<td>M8</td>
<td>24\textsuperscript{2}</td>
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<tr>
<td>ρ-Oph 102</td>
<td>M6\textsuperscript{3}</td>
<td>60\textsuperscript{3}</td>
<td>[OI] λ6300</td>
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<tr>
<td>o-Oph 32</td>
<td>M8</td>
<td>40\textsuperscript{3}</td>
<td></td>
</tr>
<tr>
<td>LS-RCrA 1</td>
<td>M6.5</td>
<td>35-72\textsuperscript{4}</td>
<td>Hα, [NII] λ6583, [SII] λ6731</td>
</tr>
</tbody>
</table>

BDs have jets: spectroastrometry in forbidden optical lines

Poster #51 (Whelan)

Very similar to TTS jets

\(M\text{wind} \sim M\text{acc}\)
Mass Accretion and Mass Loss

- Hartigan et al. 1995 (TTS in Taurus)
- Herczeg & Hillenbrand 2008 (0.035-0.17 Msun)
- Whelan et al. (0.035-0.08 Msun)
- Bacciotti et al. 2011 (0.5, 0.13 Msun)
- Rigliaco et al. in prep (0.16, 0.2Msun)

There are monsters, more at low $M_{\text{acc}}$ (?)
X-Shooter provides simultaneously accretion and outflow measurements

ρ-Oph102: ~60 M_J

Testi, Costigan, et al., in prep

- Stable in time
- Strong wind
- Dangerous to rely on a single line
Summary

✓ Formation process(es)

- BDs have disks, accrete and eject matter
- So far, BDs behave like TTS
- There are trends with the mass of the central object, but no discontinuities
- It is possible that we have not reached the “critical” mass

✓ Disk physics and evolution:

- BD disks have very low mass (no Jupiters)
- If BD disks have mm-size grains, this will set strong constraints on grain evolution; maybe easier than we think to form planetesimals in all disks
- Mass ejections in BDs: several objects with low Macc have strong mass-loss