Properties of disks around brown dwarfs and very low mass stars

Luca Ricci
California State University, Northridge

Planet-Forming disks: A workshop to honor Antonella Natta
March 7, 2019
My first meeting with Antonella
My first meeting with Antonella
My first meeting with Antonella

These radial profiles with $\gamma < 0$ do not make any sense...

Hmmm... that is peculiar...

This is all so amusing!
My first meeting with Antonella

These radial profiles with $\gamma < 0$ do not make any sense...

Hmmm... that is peculiar...

This is all so amusing!

Science **with friends** is even more fun
My first meeting with Antonella
My first meeting with Antonella
Exploring brown dwarf disks

A. Natta and L. Testi

Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy

Received 3 July 2001 / Accepted 24 July 2001

Abstract. We discuss the spectral energy distribution of three very low mass objects in Chamaeleon I for which ground-based spectroscopy and photometry as well as ISO measurements in the mid-infrared are available (Comerón et al. 2000; Persi et al. 2000). One of these stars (Cha Hα1) is a bona-fide brown dwarf, with mass 0.04–0.05 $M_\odot$. We show that the observed emission is very well described by models of circumstellar disks identical to those associated to T Tauri stars, scaled down to keep the ratio of the disk-to-star mass constant and to the appropriate stellar parameters. This result provides a first indication that the formation mechanism of T Tauri stars (via core contraction and formation of an accretion disk) extends to objects in the brown dwarf mass range.
Brown Dwarf disks – IR excess

Exploring brown dwarf disks

A. Natta and L. Testi

Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy

Received 3 July 2001 / Accepted 24 July 2001

Abstract. We discuss the spectral energy distribution of three very low mass objects in Chamaeleon I for which ground-based spectroscopy and photometry as well as ISO measurements in the mid-infrared are available (Comerón et al. 2000; Persi et al. 2000). One of these stars (Cha Hα1) is a bona-fide brown dwarf, with mass 0.04–0.05 $M_\odot$. We show that the observed emission is very well described by models of circumstellar disks identical to those associated to T Tauri stars, scaled down to keep the ratio of the disk-to-star mass constant and to the appropriate stellar parameters. This result provides a first indication that the formation mechanism of T Tauri stars (via core contraction and formation of an accretion disk) extends to objects in the brown dwarf mass range.

Natta & Testi 2001

(see also Muench+ 01, Natta+ 02, Apai+ 02, Pascucci+ 03, Mohanty+ 04)
(evidence for accretion: Jayawardhana+ 03, Muzerolle+ 03, White & Basri 04, Natta+ 04)
Brown Dwarf disks – IR excess

Natta & Testi 2001
Brown Dwarf disks – IR surveys

Table 1
Location of Observed Young BDs

<table>
<thead>
<tr>
<th>Cloud</th>
<th>Number of BDs</th>
<th>Assumed Distance</th>
<th>Assumed Age</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ophiuchus</td>
<td>3</td>
<td>125 pc</td>
<td>1–3 Myr</td>
<td>1</td>
</tr>
<tr>
<td>Taurus</td>
<td>4</td>
<td>140 pc</td>
<td>1–3 Myr</td>
<td>2</td>
</tr>
<tr>
<td>Chamaeleon I</td>
<td>12</td>
<td>160 pc</td>
<td>1–3 Myr</td>
<td>3</td>
</tr>
<tr>
<td>Chamaeleon II</td>
<td>3</td>
<td>178 pc</td>
<td>1–3 Myr</td>
<td>1</td>
</tr>
<tr>
<td>Lup I</td>
<td>1</td>
<td>150 pc</td>
<td>1–3 Myr</td>
<td>1</td>
</tr>
<tr>
<td>Lup III</td>
<td>5</td>
<td>200 pc</td>
<td>~3 Myr</td>
<td>5</td>
</tr>
<tr>
<td>Sigma Ori</td>
<td>7</td>
<td>360 pc</td>
<td>~3 Myr</td>
<td>5</td>
</tr>
<tr>
<td>Upper Sco</td>
<td>11</td>
<td>145 pc</td>
<td>~11 Myr</td>
<td>6</td>
</tr>
<tr>
<td>TWA</td>
<td>2</td>
<td>54 pc</td>
<td>8–10 Myr</td>
<td>7</td>
</tr>
</tbody>
</table>

SED fitting up to 70 (160) micron

Harvey+ 12a, 12b

(see also Apai+05, Luhman+05, Riaz+06, Scholz+06,07, Liu+15, Daemgen+16, Hendler+17)
Brown Dwarf disks – IR surveys

SED fitting up to 70 (160) micron

Harvey+ 12a, 12b

70 micron emission confined to ~ 5 au from BD, significant optical depth

(see also Apai+05, Luhman+05, Riaz+06, Scholz+06,07, Liu+15, Daemgen+16, Hendler+17)
Brown Dwarf disks – Radii before ALMA

2MASS J044427+2512

2MASS J04381+2611

Luhman+ 07

$R_{\text{disk}} \approx 20 - 40 \text{ au}$

Ricci+ 15

$R_{\text{disk}} > 20 \text{ au}$
“Understanding is seeing well”
Leonardo da Vinci (1465 - 1519)
“Understanding is seeing well”

*Leonardo da Vinci (1465 - 1519)*
ALMA Disk Surveys in nearby regions (<200 pc)

Chamaeleon I (~ 2 – 3 Myr)

Upper Sco (~ 5 – 10 Myr)

Ophiuchus (~ 1 – 2 Myr)

Lupus (~ 1 – 3 Myr)

Barenfeld+ 17
Carpenter+ 14

Ansdell+ 16
Pascucci+ 16
ALMA Disk Surveys in denser regions (~400 pc)

Orion Nebula Cluster (~ 1 – 3 Myr)

σ Orionis (~ 3 – 5 Myr)
From Flux to Mass

\[ M_{\text{dust}} = \frac{F_v \ d^2}{B_v(T_{\text{dust}}) \ \kappa_v} \]

Main Caveats:
1) Dust opacities from Beckwith+ 1990, but highly uncertain
2) Dust temperature depends on star and disk properties (flaring, radius, dust opacities, IRF,…)
3) Assumes 100% optically thin emission
Disk Surveys Results – Dust masses

$M_{\text{dust}} \propto M_{\text{star}}^{1.5 - 2.5}$, large scatter

Hint for steepening of $M_{\text{dust}}$ vs $M_{\text{star}}$ relation with age,
Suggesting faster dust evolution (loss) in VLM/BD disks

(Ansdell+ 17 (Ilaria, Paola’s Talks))
Disk Surveys Results – Dust disk sizes

105 disks in nearby regions with ALMA & SMA

Dust “effective radius”
68% of total emission

Brighter disks are larger in dust: Initial conditions?
Radial drift? (Giovanni’s talk)

\[ L_{mm} \sim R_{\text{eff}}^2 \]

Significant optical depth? (Marco)

(Andrews+ 18)
(see also Tripathi+ 17, Barenfeld+ 17, Tazzari+ 17)

(Ricci, Natta+ 12)
Disk Surveys Results – Dust disk sizes

105 disks in nearby regions with ALMA & SMA

Dust “effective radius”
68% of total emission

The effect of local optically thick regions in the long-wave emission of young circumstellar disks

$L_{\text{mm}} \sim R_{\text{eff}}^2$

Significant optical depth? (Marco)

(Ricci, Natta+ 12)
VLM/BD disks – physical structure

mm-spectral indices similar to those in T Tauri disks, test to models of dust evolution in disks (see Paola’s talk)
VLM/BD disks – physical structure

Brightest disks in Taurus around M5-M7.5
VLM/BDs as large as stellar disks
Disk in Ophiuchus is smaller, $R_{\text{disk}} < 30$ au

Ricci, Testi, Natta+ 12, 14
VLM stars/BDs surveys

17 disks around M5- M8 in Ophiuchus

All detected disks have sizes < 0.3", or < 20 au in radius: BD formation ejection? Efficient radial drift?

Testi, Natta, ...Ricci+ 16
VLM stars/BDs surveys

17 disks around M5- M8 in Ophiuchus

Testi, Natta, ... Ricci+ 16

\[ M_{\text{dust}} = \frac{F\nu \ d^2}{B\nu(T_{\text{dust}}) \ K\nu} \]

Strong effect of \( T_{\text{dust}} \) vs \( L* \) relation on \( M_{\text{dust}} \) vs \( M* \) across the HBL
VLM stars/BDs surveys

M4 - M7.75 in Taurus
VLM stars/BDs surveys

M4 - M7.75 in Taurus

No break/knee at ~ HBL

Ward-Duong+ 18
VLM stars/BDs surveys

7 disks around M5.5 - M7.5 VLM/BDs in Upper Sco

See Talk by Enrique Sanchis-Melchor for ALMA survey of Lupus BDs
BD disks with ALMA: how low in mass?

2M1207: age ~ 5 - 10 Myr, closer than all younger systems
BD disks with ALMA: how low in mass?

Dusty, gas-rich disk down to $\sim 2 \times$ deuterium burning limit

$M_{dust \ (BD)} \sim 10 \ M_{Moon}, \ M_{dust \ (planet)} < 1 \ M_{moon}$ (opt thin)

$R_{disk \ (planet)} < 0.5 \ au$ (opt thick)
BD disks with ALMA: how low in mass?

OTS 44, SpT M9.5

6 - 17 \( M_{\text{Jup}} \)

OT 44
Substructures in a VLM disk

Inner cavity at ~ 20 au
Giant Planet (> Saturn) can open it

Pinilla, Manara, Natta, Ricci+ 18
Gaps in VLM/BD disks?
~ 1 mas resolution at 3mm, 0.2 au at 200 pc, 1 au at 1 kpc
Next Generation Very Large Array (ngVLA)

~ 1 mas resolution at 3mm, 0.2 au at 200 pc, 1
Take away messages

The scaling relations established by ALMA between stellar and disk properties extend “smoothly” across the HBL and down to the DBL, although obs constraints much more limited than for stellar disks

Nearly all ALMA obs of VLM/BD disks are snapshot: Longer integrations needed to constrain the radial dust density, and molecular gas; multi-wavelength observations important for optical depths; critical for shedding light on the scaling relations

ALMA will likely detect substructures only in the brightest VLM/BD disks (ALMA 2030? ngVLA?)
Planet-Forming Clumps

A theoretical workshop to honor Leonardo Testi

March 4-8, 2039 Villa Vigoni, Italy
Thank you!
Circumplanetary disks

Very little dust around young super-Jupiter planets (or very small disks, \(\ll 0.1 - 1 \ R_{\text{Hill}}\))
(fast formation of satellites/Moons around massive giant planets?)
External photoevaporation by O stars draining mass off the disk

ONC

σ Ori

Ansdell + 17

Eisner, Ricci + 18

Disk Surveys Results 4 Environment