The SONYC survey:
Understanding brown dwarf formation through multi-object spectroscopy

Kora Mužić * European Southern Observatory, Chile

Aleks Scholz * St. Andrews, UK
Ray Jayawardhana * York U, CA
Paul Dawson * DIAS, IR

Vincent Geers * UK ATC
Motohide Tamura * NAOJ, JA
Initial mass function (IMF)

Bastian et al. (2010)
SONYC * Substellar Objects in Nearby Young Clusters

Observationally constrain the low-mass-end of the IMF in diverse star forming regions

How many of BDs are there, compared to stars?

Lower limit for star formation?

Does the environment influence the shape and the cutoff of the IMF?

How do the BDs form?
Large samples of brown dwarfs: groundwork for characterizations of their properties

Benchmark objects to calibrate models

- activity
- accretion
- atmospheres
- dynamics
- disks
- multiplicity
- spatial distribution
Why look in star forming regions?

**Reliable mass functions** (same distance, age, star-formation history)

(relatively) compact

Substellar objects are luminous (youth)

No effects of dynamical evolution

Star formation conditions directly observable

**Extinction:** makes BDs fainter, reddens also background sources

(Membership issues: spectra needed for every object)

Differential reddening

Uncertainties in models at young ages
STEP 1  deep optical and near-infrared photometry

→ selection of the candidates aims to detect photosphere

Optical: SuprimeCam/Subaru, VIMOS/VLT, MOSAIC/CTIO-4m
NIR: MOIRCS/Subaru, SofI/NTT, NEWFIRM/CTIO-4m
Public surveys: 2MASS, UKIDSS, Spitzer c2d
Chamaeleon-I

Muzic et al. (2011)

~140 candidates
We really need spectra! A lot of them...

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Band/Resolution</th>
<th>FOV</th>
<th>FOV Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIMOS/VLT</td>
<td>optical red</td>
<td>R~210</td>
<td>4 x 8' x 7'</td>
</tr>
<tr>
<td>MOIRCS/Subaru</td>
<td>HK</td>
<td>R~500</td>
<td>4' x 7'</td>
</tr>
<tr>
<td>FMOS/Subaru</td>
<td>JH</td>
<td>R~600</td>
<td>d = 30'</td>
</tr>
<tr>
<td>SINFONI/VLT</td>
<td>HK</td>
<td>R~1500</td>
<td>8''</td>
</tr>
<tr>
<td>SpeX/IRTF</td>
<td>0.8-2.5μm</td>
<td>R~100</td>
<td>slit</td>
</tr>
<tr>
<td>SofI/NTT</td>
<td>HK</td>
<td>R~600</td>
<td>slit</td>
</tr>
</tbody>
</table>
Spectral diagnostic – gravity sensitive features

**NGC 1333**
Scholz et al. (2012)

**Lupus 3**
Muzic et al. (2014)
<table>
<thead>
<tr>
<th>Survey Area [deg$^2$]</th>
<th>Cha-I</th>
<th>$\rho$ Oph</th>
<th>NGC 1333</th>
<th>Lupus 3</th>
<th>UpSco</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>1.4</td>
<td>57</td>
</tr>
<tr>
<td>Completeness [M$_{\odot}$] at $A_V$ [mag]</td>
<td>0.005</td>
<td>0.003-0.03</td>
<td>0.004-0.008</td>
<td>0.009-0.02</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>$\leq$ 5</td>
<td>$\leq$ 15</td>
<td>$\leq$ 5</td>
<td>$\leq$ 5</td>
<td>$\leq$ 5</td>
</tr>
<tr>
<td># of subst. candidates</td>
<td>142 (opt)</td>
<td>309 (opt)</td>
<td>196 (opt)</td>
<td>409 (opt-NIR)</td>
<td>96 (opt-NIR)</td>
</tr>
<tr>
<td># of spectra</td>
<td>34</td>
<td>160</td>
<td>160</td>
<td>138</td>
<td>30</td>
</tr>
<tr>
<td># of confirmed VLMOs</td>
<td>9</td>
<td>19</td>
<td>35</td>
<td>9</td>
<td>24</td>
</tr>
</tbody>
</table>
\[ \frac{N(\star)}{N(\odot)} = 2 - 5 \]

Muzic et al, 2015, subm.
**IMF** \( \frac{dN}{dM} \propto M^{-\alpha} \)

\( \alpha \sim 0.7 \)

Scholz et al. (2012)

Similar \( \alpha \) found in:

- \( \sigma \) Ori (Peña Ramírez + 2012), **Blanco-1** (Moraux + 2007),
- IC 348 (Alves de Oliveira + 2013), **Up Sco** (Lodieu + 2007),
- **\( \alpha \) Per** (Barrado y Navascues + 2002), ...

Muzic et al. , 2015, subm.
NGC1333 – the most comprehensive study

3 objects in the planetary-mass domain

The coolest one
~ L3
T ~ 2000K
mass ~ 0.006 M☉

Scholz et al. (2012b)

Substantial planetary-mass population can be excluded
Star/BD ratio
Effects of various assumptions - distance, age, extinction law, isochrones

IF $d(\text{NGC1333}) < d(\text{IC348})$
denser environment produces more BDs (??)

Scholz et al. (2013)
Census of brown dwarfs fairly complete down to De-burning limit

Free-floating objects with masses down to a few Jupiter masses exist, but their mass budget is small

Star/BD ratio is 2 – 5, but many sources of error to be understood before comparing the numbers

Summary

Spectra & photometry available on the SONYC website

http://browndwarfs.org/sonyc.html