Fundamental stellar parameters
(Low mass stars and brown dwarfs)

Pueo Nui Workshop
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Canada-France-Hawaii Telescope
Introduction

- Stellar mass function is a very important constraint on star formation models
- Photometric luminosity function is being accurately determined by IR surveys (DENIS, 2MASS), down to the brown dwarfs domain
- But still biased by unknown multiplicity fraction
- Mass/Luminosity relation poorly constrained for low mass stars, especially below 0.2 Solar mass
- Search for brown dwarfs
M-dwarfs survey

- **Goals**
  - Derive masses with a few % accuracy
  - Detect nearly all stellar companions at all separations

- **Method**
  - Combine radial velocity and adaptive optics
    - Allow to explore the full range of separations for binary systems
    - AO + coronagraphy provides high angular resolution and high dynamic range
**M-dwarfs survey**

- **Sample**
  - 120 (200) M-dwarfs with \(d < 9\) pc (12pc) + 30 from old programme (12 orbits) initiated with CORAVEL + IR speckle

- **Collaboration (1997-2003)**
  - CFHT: T. Forveille
  - Geneva: M. Mayor, D. Ségransan, S. Udry
  - Also: F. and C. Roddier, E. Martin
M-dwarfs survey

- **Instruments**
  - ELODIE (OHP 1.93-m)
    - 15 to 70 m/s; V < 12
    - Earlier results from CORAVEL (300 m/s)
  - PUEO + KIR (CFHT)
    - Down to 0.08” separation (0.8 AU at d = 10 pc)
    - Lyot coronagraph with 1” mask (ΔK = 13 at 2”)
    - 1-5 mas accuracy in astrometry using WFS data reconstruction and AOPHOT (Véran & Beuzit, 98)
    - Earlier results obtained with ADONIS
**M-dwarfs survey**

- **Instruments**
  - NAOS + CONICA (July 2003…)
    - Down to 0.03”” separation (0.3 AU at d = 10 pc)
    - Lyot coronagraph with 0.7”” mask ($\Delta K = 11$ at 1””)
    - New 4Q coronagraphic mode (2004)
    - Differential imaging mode (2004)
    - CIA coronagraph available 2005?
    - WFS reconstruction and/or deconvolution methods
      - MISTRAL (Fusco et al., 2002)
Observations

AIC on PUEO (2000)

V = 10
ΔK = 4.2
Brg. texp = 10 s
Detection limits

![Graphs showing detection limits for substellar systems.](image)
Detection limits
Mass-luminosity function

- Improved mass/luminosity relation
  - Only PUEO data at the moment: ~ 32 masses
  - NACO expected to provide new masses in the next 2 years (3 new resolved systems July 03)
  - Better accuracy needed at short wavelength
  - Effect of metallicity (at short wavelength)

- Example of mass accuracy: Gl 570
  - Mass A = 0.568 +/- 0.012 Msun (2.2%)
  - Mass B = 0.382 +/- 0.006 Msun (1.7%)
Mass-luminosity function

Delfosse et al., 2000
Multiplicity fraction

- Sub-sample of 94 M-dwarfs: $d < 9.25$ pc, $M_v < 15$ and spectral types from M0 to M6
- Multiplicity fraction of M-dwarfs = $25.7 \pm 3\%$
- Corrected from instrumental effects by Monte-Carlo simulations
- Multiplicity fraction decreases with mass of primary:
  - OB stars ~ 70\%
  - G dwarfs ~ 57\% (Duquennoy & Mayor, 1991)
- G and M dwarfs show very similar separation distributions at short periods
- Lack of companions around M-dwarfs at large periods
Multiplicity fraction

![Graph showing multiplicity fraction with different data sets represented by different lines.](image-url)
Remarks

- No BD at $d < 3$ AU
- A lot of our targets have faint companions with $\Delta K > 8-9$ (follow-up observations in progress).
- New extra-solar planet around Gl 876 (ELODIE), only one around M-dwarfs
Conclusion and future

- Improved mass/luminosity relation for very low mass stars
- Close interaction with the Lyon group (Allard, Baraffe, Chabrier) to adjust models
- Multiplicity fraction of M-dwarfs = 25.7 ± 3%
- Detailed analysis of systems parameters on-going
- New/improved masses expected from NACO soon
- Follow-up of observed faint companions on-going
- Program to be extended to L dwarfs on NACO + LGS (could be started with IR wavefront sensor ~ 30 targets)
Pueo/Kir AO observations of MBM 12

d = 65 (275) pc
Age = 2 Myr
14 stars known
(Hearty et al. 2000)
(Luhman 2001)

Observations of 11 members (Dec 2001)
Coronagraphy (⌀ = 0.9″) coupled with
the AO system PUEO/KIR + GRIF (CFHT)
Collaboration: G. Chauvin, A.-M. Lagrange, F.
Ménard, T. Fusco, J.-L. Beuzit, D. Mouillet, J.-C.
Augereau
Detection of seven close binaries unknown

An uncertain wide binary around LkHα 264

A faint nebulosity close to LkHα 263 AB
Study of the binarity fraction

Comparison with multiplicity of G-K field dwarfs and M field dwarfs
We considered:
- same mass ratio $q=0.1$, i.e. $\Delta K = 2.9$ according to BCAH98 model
- same physical separation range
**Binarity excess in the MBM 12 association?**

<table>
<thead>
<tr>
<th>Associations</th>
<th>Nobs</th>
<th>bf (%)</th>
<th>bf (MS) (%)</th>
<th>Age (Myr)</th>
<th>d (pc)</th>
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<tbody>
<tr>
<td>MBM12</td>
<td>11</td>
<td>54.</td>
<td>18.-23.</td>
<td>2</td>
<td>275</td>
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<tr>
<td>TW hydrae</td>
<td>19</td>
<td>32.</td>
<td>19.-24</td>
<td>10-20</td>
<td>65</td>
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<tr>
<td>IC348</td>
<td>19.5</td>
<td></td>
<td></td>
<td>2</td>
<td>320</td>
</tr>
</tbody>
</table>

- **Binary Excess?**
- **Binary fraction:** $bf \sim 54\%$
- (19.5%, IC348; Duchêne et al. 99)

*Binary fraction inversely correlated to the stellar density*
VLT/NACO observations of HIP 6856
A possible 3-5 Jup mass companion?

Detection of 2 faint companions with NACO in coronagraphic mode Ks filter, Exp. Time = 150 s
Separations: CCb (4.8”); CCc (2.8”)
$\Delta Ks$: CCb (10.25); CCc (12.2)

Astrometry needed to actually discriminate between background object and physical companion
VLT/NACO detection limits for HIP 6856

Detection limits (VLT-NACO)
- upper curve: classical imaging
- lower curve: coronagraphic mode
- dotted: ADONIS coronagraphic mode

HIP 6856 CCb
HIP 6856 CCc
VLT/NACO observations of GSC8047-0232
A 20-30 Jup mass companion

- Coronography J, H and Ks

- Spectroscopy needed in Ks to confirm the sub-stellar nature of this object

VLT/NACO GTO 70 Dec. 2002

First detection with ADONIS - 2001

Ks filter, Exp. Time = 35 s
Sep. = 3.28” ; ΔK = 8.5
And Pueo Nui?

- Only AO system accessible to French astronomers in the Northern hemisphere!
- Better resolution (diffraction-limit in R)
  - More objects with RV and AO data (more masses with very high accuracy)
- Better correction AND stability
  - New coronagraphic modes (AIC, 4-Q, etc.)
  - Differential imaging (Trident)
  - Improved deconvolution → astrometric accuracy
  - Extension to the visible: imaging and low-resolution spectroscopy