The SHINE exoplanet survey

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The SHINE survey

- Near-IR imaging survey of exoplanets
- 200 nights
- SPHERE instrument at VLT
  - IRDIS (1.6um, 12” FoV)
  - IFS (0.9-1.4um, 1.7” FoV)
- Statistical sample: 400-600 targets
- Special targets: 50 targets (disks, known companions etc)
Science with SHINE

- New planet discoveries
- Physics of giant planets
  - Young L, T, Y objects
  - Atmospheres
  - Mass-luminosity
  - Accretion and evolution
- System architectures
  - Planet-disk and planet-planet interactions
- Giant planet occurrence and formation

An amazing animation of IFS data for HIP 65426 b that doesn't work on PDF
Characterisation of known systems: Orbits, Atmospheres, Architectures, Variability....

Planet search, 1st epoch visit

Follow-up of most promising exoplanet candidates

Early-Stat

Final-Stat

80%
New discoveries
HIP 65426 b

- Host: A2, 1.96M☉
- LCC member (14Myr)
- 92 AU
- L5-L7
- 6-12 M_{Jup}
- 1300-1600K
- log(g) = 4-5 dex
- R = 1.5 R_{Jup}

First new planet discovery
Chauvin et al. 2017, A&A
HIP 64892 B

- Host: B9, 2.35$M_\odot$
- LCC member (16Myr)
- 159 AU
- M8-L0
- 29-37 $M_{\text{Jup}}$
- 2500-2700K
- $\log(g) = 3.5-4.5$ dex
- $R = 2.3 \, R_{\text{Jup}}$

First new brown dwarf discovery
Cheetham et al. 2018, A&A (accepted)
and the newest addition...
PDS 70 b

- Host: K7, 0.76M☉
- UCL member (5.4 Myr)
- 22 AU
- mid-late L
- 6-12 M_{Jup}

Keppler, Benisty, Mueller, Henning et al. 2018
Mueller, Keppler, Henning et al. 2018
and ESO press release

K1K2 2018-02-24

(NACO, ISPY)
PDS 70 b

See poster 36 by M. Samland for more details!
Early Statistical Analysis
Characterisation of known systems: Orbits, Atmospheres, Architectures, Variability....

Planet search, 1st epoch visit

Follow-up of most promising exoplanet candidates

Early-Stat

Final-Stat
Statistical Constraints

Direct Imaging
\( M = 5 - 13 \, M_{\text{Jup}}, a = 30 - 300 \, \text{AU} \)

Radial Velocity
\( K > 20 \, \text{m/s}, a < 2.5 \, \text{AU} \)

- **BA**
  - \( 2.8^{+3.7}_{-2.3} \% \)

- **All**
  - \( 0.6^{+0.7}_{-0.5} \% \)

Bowler (2016), PASP
Statistical Constraints

Sample

Completeness

Candidates

Population

Cake with candles
Candidates
Candidates

ML sequence of field objects

 Undefined candidates

 Excluded candidates

 Exclusion region

TY sequence of field objects
Completeness

SHINE detection probabilities (180 stars)

Naco-LP detection probabilities (200 stars)

Mass conversion with Baraffe et al. models (Baraffe+ 2003, 2015)

+ Monte-Carlo analysis with MESS tool (Bonavita+ 2013)
Bayesian estimation of the likelihood (Lafrenière+ 2007; Vigan+ 2012)

Frequency estimation in several bins of mass and semi-majors axis

Hypotheses:
- all spectral types
- nominal age for stars
- undefined candidates ignored ➔ background

- companions distribution:
  - flat in mass
  - flat in semi-major axis

Not physical!!
Comparison with Models

- Population synthesis models of Forgan et al. (2013, 2015)
- Gravitational Instability + scattering
Comparison with Models

- Frequency estimation compatible with NaCo-LP results (Vigan et al. 2017)
- Similar results without and with scattering

Next step: comparison to CA models (Mordasini et al.)
SHINE

- 3.5 / 5 years
- 7 Press releases (ESO, CNRS, MPIA, INAF, ...)
- Lots of interesting results from known objects
- Many newly imaged disks
- Several new detected planets and brown dwarfs
- More interesting candidates
- Early Statistical analysis in progress (Desidera+ 2018, Langlois+ 2018, Vigan+ 2018)
- Final statistical analysis ~2021
Intermediate SHINE sample

- 167 targets
- 4+1 priority bins:
  - P4 to P1 for standard targets
  - P0 for special targets
- observed by order of priority + external parameters (date, obs. conditions, etc)

Desidera et al. in prep.

- intermediate sample representative of the full SHINE sample
- no significant bias in spectral type/distance/age
- but bias towards P0 targets because of known companions
**Known detections in the sample**

**Priority P1:** 60% probability of observation ($P_{obs}$)  
**Priority P2:** 35% probability of observation  
**Priority P4:** 1% probability of observation

Change to P0 creates a real bias  
$\rightarrow$ count "effective detections" for the analysis

$$N_{\text{eff}} = \sum_{i=1}^{N} P_{\text{obs},i} N_{\text{det},i} = 7.31$$

<table>
<thead>
<tr>
<th>Star</th>
<th>Spectral type</th>
<th>Semi-major axis [au]</th>
<th>Mass [M$_{\text{Jup}}$]</th>
<th>$q$ M$_{\text{Jup}}$/M*</th>
<th>Original priority</th>
<th>Updated priority</th>
<th>Effective detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>β Pictoris</td>
<td>A3</td>
<td>8-10</td>
<td>12-13</td>
<td>0.7 %</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>HR8799</td>
<td>A5</td>
<td>17, 27, 43, 68</td>
<td>4-6, 5-9, 5-9, 5-9</td>
<td>0.2-0.6%</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>HD95086</td>
<td>A8</td>
<td>52</td>
<td>3-7</td>
<td>0.4 %</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>HIP65426</td>
<td>A2</td>
<td>92</td>
<td>6-12</td>
<td>0.3-0.6%</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>Gl504</td>
<td>G0</td>
<td>&gt;27</td>
<td>12-33</td>
<td>0.9-2.5%</td>
<td>P2</td>
<td>P0</td>
<td>0.35</td>
</tr>
<tr>
<td>S1 Eri</td>
<td>F0</td>
<td>13</td>
<td>2-10</td>
<td>0.1-0.7%</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>HIP64892</td>
<td>B9</td>
<td>147-171</td>
<td>29-37</td>
<td>1.3-1.7%</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>HIP107412</td>
<td>F5</td>
<td>10-20</td>
<td>15-30</td>
<td>1.1-2.2%</td>
<td>P4</td>
<td>P0</td>
<td>0.01</td>
</tr>
<tr>
<td>PZ Tel</td>
<td>G9</td>
<td>70-80</td>
<td>38-54</td>
<td>3.3-4.7%</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>η Tel</td>
<td>A0</td>
<td>136</td>
<td>20-50</td>
<td>1.0-2.4%</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>GSC 8047-0232</td>
<td>K2</td>
<td>280</td>
<td>15-35</td>
<td>1.6-3.8%</td>
<td>P2</td>
<td>P0</td>
<td>0.35</td>
</tr>
<tr>
<td>CD -35 2722</td>
<td>M1</td>
<td>50-152</td>
<td>23-39</td>
<td>4.0-6.8%</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>AB Pic</td>
<td>K1</td>
<td>250</td>
<td>13-30</td>
<td>1.3-3.0%</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
<tr>
<td>HIP78530</td>
<td>B9</td>
<td>700</td>
<td>23</td>
<td>1.0 %</td>
<td>P1</td>
<td>P0</td>
<td>0.60</td>
</tr>
</tbody>
</table>
Investigating temperature/gravity/clouds

**Today:** most imaged exoplanets are young L and early-T types,

**Peculiar properties:**
- Redder at L/T transition,
- CH4 absorption inhibited
- Underluminous for various cases,
- Enhanced photometric variability?

> Clouds/Gravity & Temperature

**Exploring atmospheric diversity:**
- Building an homogeneous spectral sequence with SHINE,
- Testing predictions of models (Teff, log(g), Fe/H), cloud modelling, non-equl. processes,
- Comparison with young BD properties; Formation processes footprint?