The CHESS survey of the L1157-B1 shock

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on behalf of the CHESS outflow team


Herschel’s view of Star and Planet formation  Grenoble, 20th-23th March 2012
OUTLINE

• The L1157 chemically rich outflow

• CHESS Observations

• Molecular content in L1157-B1

• Shock structure and comparison with models

• Summary and Conclusions
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The L1157 chemically rich outflow

- **Spitzer composite image -3.5/4.5/8 µm** (Looney et al. 2007)

- **IRAC 8 µm (grey)** + **CO(2-1) (contours)** (Looney et al. 2007, Bachiller et al. 2001)

- **PdBI observations**: **CO(1-0)** (Gueth et al. 1996) + **SiO(2-1)** (Gueth et al. 1998) + **CS(2-1)** (Benedettini et al. 2007)

- **Herschel-PACS H\(_2\)O image @179 µm** (Nisini et al. 2010)

- **Precessing molecular outflow associated with several bow shocks seen in CO** (Gueth et al. 1996) and **H\(_2\)** (Neufeld et al. 2009; Nisini et al. 2010): **B1** is the brightest shocked region

- **Distance of 250 pc; powered by a Class 0 source**

- **Most chemically rich outflow known so far**: **SiO, SO, NH\(_3\), CH\(_3\)OH, C\(_2\)H\(_5\)OH, H\(_2\)O**, and many other molecules!

- **B1 shock**

- **B2**
The L1157 chemically rich outflow

Gueth et al. 1998; Benedettini et al. (2007); Codella et al. (2009)

CH$_3$CN vs. CH$_3$OH  CH$_3$CN vs. SiO  CH$_3$CN vs. CS

Complex and clumpy structure of the B1 shock, with typical shock tracers peaking at different positions.

**L1157-B1** is an excellent laboratory to investigate the effects and the structure of shocks on the gas chemistry.
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- Pointed observations: CO, H$_2$O, CI, CII, NH, NH$_2$, HF, HCl, CH$^+$
- **PACS:** full spectrum 55-95.2 $\mu$m and 101.2-210 $\mu$m. Stared mode: 5x5 spaxels of 9.4” (FOV of 47”x47”)
- **SPIRE:** full spectrum 190-672 $\mu$m
- **IRAM 30m survey**

### HIFI Band

<table>
<thead>
<tr>
<th>Band</th>
<th>Freq. (GHz)</th>
<th>Lines of interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>488-555</td>
<td>CI, HDO</td>
</tr>
<tr>
<td>1b</td>
<td>555-636</td>
<td>CO(5-4), o-H$<em>2$O $1</em>{10-1_{01}}$</td>
</tr>
<tr>
<td>2a</td>
<td>680-700</td>
<td>CO(6-5)</td>
</tr>
<tr>
<td>2b</td>
<td>734-754</td>
<td>H$<em>2$S, p-H$<em>2$O $2</em>{11-2</em>{02}}$</td>
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<tr>
<td>4a</td>
<td>984-1004</td>
<td>p-H$<em>2$O $2</em>{02-1_{11}}$</td>
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<tr>
<td>4b</td>
<td>1094-1114</td>
<td>o-H$<em>2$O $3</em>{12-3_{03}}$</td>
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<tr>
<td>5a</td>
<td>1110-1170</td>
<td>CO(10-9), o-H$<em>2$O $3</em>{21-3_{12}}$</td>
</tr>
<tr>
<td></td>
<td>1150-1179</td>
<td></td>
</tr>
<tr>
<td>6b</td>
<td>1600-1670</td>
<td>CO(14-13), o-H$<em>2$O $3</em>{12-1_{01}}$</td>
</tr>
</tbody>
</table>
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• **Molecular content in L1157-B1**

• Shock structure and comparison with models

• Summary and Conclusions
### Molecular content in L1157-B1

<table>
<thead>
<tr>
<th>Species</th>
<th>Lines</th>
<th>HIFI</th>
<th>SPIRE</th>
<th>PACS</th>
<th>$E_{up}$ (K)</th>
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<tbody>
<tr>
<td>CO</td>
<td>18</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>83 - 1397</td>
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<tr>
<td>$^{13}$CO, $^{18}$O</td>
<td>5,1</td>
<td>5,1</td>
<td>-</td>
<td>-</td>
<td>79 - 291</td>
</tr>
<tr>
<td>H$_2$O (o/p)</td>
<td>14</td>
<td>8 (5,3)</td>
<td>2 (p)</td>
<td>6</td>
<td>26 - 323</td>
</tr>
<tr>
<td>OH</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>6</td>
<td>120 - 291</td>
</tr>
<tr>
<td>CI</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>228 - 253</td>
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<tr>
<td>HCO$^+$</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>24 - 63</td>
</tr>
<tr>
<td>H$_2$CO (o/p)</td>
<td>12</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>90 - 120</td>
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<tr>
<td>CH$_3$OH</td>
<td>63</td>
<td>63</td>
<td>-</td>
<td>-</td>
<td></td>
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<tr>
<td>HCN</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>89 - 119</td>
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<tr>
<td>NH$_3$ (o)</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>28</td>
</tr>
<tr>
<td>H$_2$S (o/p)</td>
<td>3</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>48 - 86</td>
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<tr>
<td>CS</td>
<td>3</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>129 - 183</td>
</tr>
<tr>
<td>SiO</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>163</td>
</tr>
<tr>
<td>NO</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HCl</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>All ($3 \sigma$)</td>
<td>113</td>
<td>13</td>
<td>24</td>
<td></td>
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</table>

- 17 molecular species detected with HIFI
- 3 new species in outflows: NO, HCl (Codella et al. 2012) see poster by Codella et al. and N$_2$H$^+$
- Species searched for but not detected with HIFI: CH$^+$, HF, NH, NH$_2$, HDO, C$^+$

**Ongoing projects:**

- N-bearing species (HIFI and IRAM) see poster by Vasta et al. from simple (PN, NS, CN) to very complex molecules (CH$_2$CHCN…).
- N$_2$H$^+$ detected for the first time in outflows
- H$_2$O emission (HIFI and PACS) see poster by Busquet et al.
Molecular content in L1157-B1

**HCl (1-0) @625.9 GHz towards L1157-B1**

Codella, Ceccarelli, Bottinelli et al. (2012)

- HCl emission does not come from the cloud component
- HCl comes from compressed ($>10^5$ cm$^{-3}$) gas

- $X$(HCl) around $10^{-9}$: similar to that observed in protostars
- BUT grain erosion in the shock has returned up to 10% of Si to the gas phase
- chlorine is depleted into a more refractory phase than silicon?
- HCl is not the main reservoir of chlorine?

See poster by Codella et al.
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• **Shock structure and comparison with models**
• Summary and Conclusions
Lefloch et al. (2010) derived the physical condition from low-$J_{up}$ CO lines:

- **Low-velocity component** (LVC): $-7 < v < 4$ km/s, molecular rich and relatively cold ($T \sim 100$ K) and high density gas
- **High-velocity component** (HVC): $-30 < v < -7$ km/s, molecular poor and associated with hot gas ($T > 400$ K) at moderate densities
Shock structure and comparison with models

The high-velocity gas

Excellent match in the HV regime for high-$J_{up}$ CO and SiO

PACS CO maps
(Benedettini, Busquet, Lefloch et al. 2012)

- PACS CO lines associated with HVC
- B1 position: PACS and HIFI data to constrain temperature and density using LVG model

SiO HVC: size $\sim 7''$

$T = 200 - 600$ K
$n(H_2) > 10^5$ cm$^{-3}$
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Shock structure and comparison with models

- OH and [OI] peak at the same position of CO, at the rear of the bow shock
- They also correlate with [FeII] (Neufeld et al. 2009)
- Tracers of postshock gas trace the extended bow shock

Benedettini et al. (2012); SiO: Gueth et al. (1998); CH$_3$CN: Codella et al. (2009); H$_2$: Caratti o Garatti et al. (2006)
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Shock models
(Flower & Pineau des Forêts 2010, Neufeld & Hollenbach 1994)

[OI] brightness, total CO, OH and [OI] luminosity are consistent with dissociative J-type shock models.
The low-velocity gas

- NH$_3$, H$_2$CO, and CH$_3$OH emit at low outflow velocities; H$_2$O is bright at high velocities (Lefloch et al. 2010, Codella et al. 2010)

➤ Modelling of NH$_3$ and H$_2$O profiles (Viti et al. 2011) at B1 position:

UCL_CHEM (Viti et al. 2004) + parametric shock model (Jimenez-Serra et al. 2008)
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  - UCL_CHEM (Viti et al. 2004) + parametric shock model (Jimenez-Serra et al. 2008)

Differences are purely chemical: NH$_3$ is destroyed at very high T while destruction of H$_2$O has very high barrier. Explained by C-type shock

- $v_{\text{shock}} \sim 40 \text{ km/s}$, $n_H \sim 10^5 \text{ cm}^{-3}$, $T_{\text{max}} \sim 4000 \text{ K}$
Comparison with C+J shock model that fits $H_2$ and SiO in L1157-B1 (Gusdorf et al. 08b)

Cabrit et al. in prep

Shock parameters: $n_H = 10^4$ cm$^{-3}$, $V_s = 20$ km/s, age $\sim 1000$ yrs, $b = 0.45-2.0$
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We obtained a complete chemical census of a shocked material in L1157-B1.

A comprehensive picture of outflow shock region L1157-B1 is emerging, showing a chemical and physical differentiation.

Two CO gas components are detected:

- Hot component at T~600 K, n(H$_2$)~10$^5$ cm$^{-3}$
- Warm component at T~130 K, n(H$_2$)~2x10$^5$ cm$^{-3}$

Comparison with shock models suggests that the hot component, at the rear of the bow shock, arises from a dissociative J-type shock.

At the B1 position, NH$_3$ and H$_2$O line profiles agree with a C-type shock scenario.
THANKS!