HERSCHHEL/PACS observations of young (Class II) sources driving outflows

Linda Podio
Kapteyn Institute – Groningen – The Netherlands

and the GASPS team
Outline:

Introduction: accretion/ejection process in YSO
  role of stellar jets in the star formation process
  theoretical models for jet launch
  jets observational properties
  Multi-λ studies: importance & problems

First results from GASPS/PACS data:

FIR maps of outflow from Class II sources (DG Tau B, DG Tau, RW Aur, T Tau, RY Tau, ...)
  Extended, velocity-shifted emission in atomic and/or molecular lines
  Estimate of mass flux rate > mass ejection/mass accretion

Open issues:
  Desentangling jet/disk emission in the central spaxel
  OI63-cont in jet and non-jet sources
  Line ratios
  HIFI observations > velocity resolved line profiles
Outline:

Introduction: accretion/ejection process in YSO
- role of stellar jets in the star formation process
- theoretical models for jet launch
- jets observational properties
- Multi-\(\lambda\) studies: importance & problems

First results from GASPS/PACS data:
- FIR maps of outflow from Class II sources (DG Tau B, DG Tau, RW Aur, T Tau, RY Tau, ...)
  - Extended, velocity-shifted emission in atomic and/or molecular lines
  - Estimate of mass flux rate > mass ejection/mass accretion

Open issues:
- Desentangling jet/disk emission in the central spaxel
- OI63-cont in jet and non-jet sources
- Line ratios
- HIFI observations > velocity resolved line profiles
Accretion/ejection in the star formation process

- Molecular cores
- Gravitational collapse
- Embedded young star
- Accretion disk
- Jet
- Planetary system
- T Tauri star: $t = 10^6 - 10^7$ yrs
- Main Sequence star: $t > 10^7$ yrs

Time periods:
- $10^4$ - $10^5$ yrs
- $10^{10}$ yrs

Distances:
- 1 pc
- 100 AU
- 50 AU
- 10 000 AU
Why studying stellar jets?

The existence of HH jets may help to justify:

- Removal of excess angular momentum
- Dispersion of infalling envelope
- Injection of turbulence for cloud support?

Other interesting issues:

- Jet structure traces past events in star/disk system
- Space laboratory for shock physics/chemistry
- Study of embedded sources
- Similarity with AGN jets
Properties of jets from young stars...

- **Dg Tau B**
  - High speed: \( V_j = 100 - 400 \text{ km/s} \)
  - Highly supersonic: \( M = V_j / C_s \approx 10 - 30 \)
  - Mild shocks: \( V_s \approx 30 - 70 \text{ km/s} \)

- Often bipolar, but asymmetric - perpendicular to disk plane - knotty

- Observed Width: 10 - 200 AU
- Observed Length: a few hundreds AU to a few pc

Association with accretion disk

- High speed: \( V_j = 100 - 400 \text{ km/s} \)
- Highly supersonic: \( M = V_j / C_s \approx 10 - 30 \), but mild shocks \( V_s \approx 30 - 70 \text{ km/s} \)
Models for jet formation

to produce a fast collimated jet one needs an accretion disk + magnetic field

Magneto-centrifugal process

DISK WIND
Blandford & Payne 1982
Ferreira 1997
Konigl & Pudritz 2000 (PPIV)

STELLAR WIND
Sauty et al. 2002

MASS FLUX RATE = \( \dot{M}_{\text{jet}} \)
to understand accretion/ejection interplay

\( \dot{M}_{\text{jet}}/\dot{M}_{\text{acc}} \approx 0.01 - 0.1 \) in MHD WIND MODELS

Figure 1.3 Development of the azimuthal field. With each rotation of the field line a loop of field is added to the flow at the Alfvén surface.
Observational properties of jets & outflows

**optical**
- 0.3μm
- $H\alpha$, [SII], [OI], [NII], [CaII], [FeII], [OIII], [CI], [SIII], [OIII]

**NIR**
- 0.6 μm
- $H_2$, [FeII], HI, [N I], [S II], [SIII] ...

**MIR**
- 2.5μm
- $H_2$, [FeII], [SiII], [Si] ...

**FIR**
- $H_2 O$, $H_2$, $H_2 S$, high-J CO, OH, [CII] 158 um, [OI]63um, 145 um

**(sub-) mm**
- CO, CS, SiO, SO

---

hot, partially ionized gas:
- $T \sim 10^4$ K
- $Xe \sim 0.01$-0.6

warm gas:
- $T \sim 100$-5000 K

cold gas:
- $T \sim 10$-100 K

---

telescopes from ground (ESO, KECK)
telescopes from space (HST)
interferometer (VLTI/AMBER)
telescopes from space
- SPITZER (MIR)
- HERSCHEL (FIR)

mm telescopes, interferometers
- SMA
- IRAM
- ALMA
The importance of multi-wavelengths analysis

Ionic and atomic lines:
- dissociative J-shocks
- non-dissociative C-shocks

Molecular H$_2$ emission

Collimated optical jet + molecular outflow

IR lines to observe the embedded part of the jet

Optical lines

(Hollénbach et al., 1997)

(Mitchell et al., 1994)

(Reipurth et al., 2000)
Comparison of observations taken at different lambda (e.g., optical/NIR and FIR obs) IS NOT EASY!

1. ANGULAR/SPECTRAL RESOLUTION PROBLEM

2. SENSITIVITY PROBLEM
1. ANGULAR/SPECTRAL RESOLUTION PROBLEM

OPTICAL

seeing-limited imaging/spectroscopy:
~ 0.6-0.8” > 100 AU
Dv ~ 8 km/s
HST:
~ 0.1” > 14 AU

(Eisloeffel & Mundt 1998)
1. ANGULAR/SPECTRAL RESOLUTION PROBLEM

**OPTICAL**
seeing-limited imaging/spectroscopy:
~ 0.6-0.8” > 100 AU
Dv ~ 8 km/s

**HST:**
~ 0.1” > 14 AU

**FIR**
ISO/LWS (D=60cm)
~ 80” > 11200 AU
R ~ 200-300

---

(Eisloeffel & Mundt 1998)

---

Nisini et al. 2000
1. ANGULAR/SPECTRAL RESOLUTION PROBLEM

**OPTICAL**
seeing-limited imaging/spectroscopy:
~ 0.6-0.8” > 100 AU
Dv ~ 8 km/s
HST:
~ 0.1” > 14 AU

**FIR ISO/LWS**
(D=60cm)
~ 80” > 11200 AU
R ~ 200-300

**FIR HERSCHEL/PACS**
(D=3.5m)
~ 10” (λ < 120um) > 1400 AU
Dv~88 km/s (at 63um)

(Eisloeffel & Mundt 1998)
1. Angular/Spectral Resolution Problem

Optical
seeing-limited imaging/spectroscopy:

- \(0.6-0.8'' > 100 \text{ AU}\)
- \(Dv \sim 8 \text{ km/s}\)

HST:

- \(0.1'' > 14 \text{ AU}\)

FIR
ISO/LWS
\((D=60\text{cm})\)

- \(80'' > 11200 \text{ AU}\)
- \(R \sim 200-300\)

FIR
HERSCHEL/PACS
\((D=3.5\text{m})\)

- \(10'' (\lambda < 120\mu\text{m}) > 1400 \text{ AU}\)
- \(Dv \sim 88 \text{ km/s (at 63}\mu\text{m})\)

FIR
HERSCHEL/HIFI
\((D=3.5\text{cm})\)

- \(13'' - 39'' > 1-6e3 \text{ AU}\)
- \(Dv \sim 0.01 \text{ km/s}\)

*(Eisloeffel & Mundt 1998)*
2. SENSITIVITY PROBLEM

ISO/LWS (D=60cm): \(1\times10^{-15} \text{ W/m}^2\) → jets from Class 0/I

Class 0/I ISO spec (Nisini et al. 1996)

Molinari et al. 2001
Ceccarelli et al. 1997
+ T Tau (Spinoglio et al. 2000)

Herbig Ae/Be, ISO fluxes (Lorenzetti et al. 2002)

HERSCHEL/PACS (D=3.5m): \(1\times10^{-18} \text{ W/m}^2\) → jets from Class II

Linda Podio
Goteborg, September 2010
Outline:

Introduction: accretion/ejection process in YSO
- role of stellar jets in the star formation process
- theoretical models for jet launch
- jets observational properties
- Multi-λ studies: importance & problems

First results from GASPS/PACS data:
- FIR maps of outflow from Class II sources (DG Tau B, DG Tau, RW Aur, T Tau, RY Tau, ...)
  - Extended, velocity-shifted emission in atomic and/or molecular lines
  - Estimate of mass flux rate > mass ejection/mass accretion

Open issues:
- Desentangling jet/disk emission in the central spaxel
- OI63-cont in jet and non-jet sources
- Line ratios
- HIFI observations > velocity resolved line profiles
**GASPS: GAS evolution in Protoplanetary System (PI: B. Dent)**

Survey of atomic/molecular gas and dust in ~ 200 disks  
wide range of ages: 1-30 Myr  
disk masses: $10^{-2} - 10^{-5}$ M$_{\text{sol}}$  
not young/embedded sources: Class II/III  
spectral types (A to M)  
Nearby star-forming regions (Taurus, ηCha, βPic, Herbig Ae/Be, ...): d ~100-200 pc

---

### MOLECULAR LINES:
- H$_2$O, OH, high-J CO ($J \geq 18$)

### ATOMIC LINES:
- [OI] 63, 145 um, [CII] 158 um

> **GAS in the JET**
> **GAS in the DISK**

the GASPS survey includes  
a number of well-known jet sources:  
Taurus CTTSs (i.e., Class II)  
associated to bright optical jets  
which have never been studied at FIR wavelengths!

<table>
<thead>
<tr>
<th>Setting</th>
<th>Grating order</th>
<th>Species</th>
<th>Transition</th>
<th>Wavelength ($\mu$m)</th>
<th>$E_{\text{upper}}$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>[OI]</td>
<td>3P1-3P2</td>
<td>63.184</td>
<td>228</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>DCO$^+$</td>
<td>J=22-21</td>
<td>189.570</td>
<td>874</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>H$_2$O</td>
<td>o 4-23 - 3-12</td>
<td>78.741</td>
<td>432</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>OH</td>
<td>1/2 - 3/2 hfs</td>
<td>79.11/79.18</td>
<td>182</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>CO</td>
<td>J=33-32</td>
<td>79.360</td>
<td>3092</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>[CII]</td>
<td>2P3/2 - 2P1/2</td>
<td>157.741</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>H$_2$O</td>
<td>p 3-31 - 4-04</td>
<td>158.309</td>
<td>410</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>H$_2$O</td>
<td>p 3-22 - 2-11</td>
<td>89.988</td>
<td>297</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>CO</td>
<td>J=29-28</td>
<td>90.163</td>
<td>2400</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>H$_2$O</td>
<td>o 2-12 - 1-01</td>
<td>179.527</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>CH$^+$</td>
<td>J=2-1</td>
<td>179.610</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>H$_2$O</td>
<td>o 2-21 - 2-12</td>
<td>180.488</td>
<td>194</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>CO</td>
<td>J=36-35</td>
<td>72.843</td>
<td>3700</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>H$_2$O</td>
<td>p 4-13 - 3-22</td>
<td>144.518</td>
<td>396</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>CO</td>
<td>J=18-17</td>
<td>144.784</td>
<td>945</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>[OI]</td>
<td>3P0 - 3P1</td>
<td>145.525</td>
<td>326</td>
</tr>
</tbody>
</table>
A multi-wavelength study of DG Tau B

**OPTICAL**
seeing-limited imaging/spectroscopy:
~ 0.6-0.8” > 100 AU
Dv ~ 8 km/s
Mundt & Fried 1983
Mundt et al. 1991
Eisloeffel et al. 1998

**HST:**
~ 0.1” > 14 AU
Padgett et al. 1999
Stapelfeldt et al. 1997

**FIR**
HERSCHEL/PACS
pixel ~ 9.4” > 1400 AU
Dv ~ 88 km/s (at 63um)

**MM**
Owens Valley mm array
~ 4” > 600 AU
Dv ~ 0.2-2.6 km/s
Mitchell et al. 1994, 1997

(Eisloeffel & Mundt 1998)
OPTICAL observations > HOT, high-velocity, collimated atomic jet

JET KINEMATICS:
\[ V_{\text{blue}} \approx 330 \text{ km/s} \quad \text{-----} \quad V_{\text{red}} \approx 140 \text{ km/s} \]

GAS PHYSICAL PROPERTIES:
- dense \( (n \approx 10^3 - 10^4 \text{ cm}^{-3}) \)
- hot \( (T_e \approx 5000 - 30000 \text{ K}) \)
- highly ionized \( (x_e \approx 0.1 - 0.8) \)

JET WIDTH (d < 5"):
- \( R_{\text{blue}} \) up to 100 AU
- \( R_{\text{red}} \) \( \approx \) 50 AU

KECK-HIRES SPEC STUDIES (~0.8", \( Dv \approx 8 \text{ km/s} \))
(Podio, Eisloffel et al., in prep)
mm observations > COLD, molecular, wide-angle outflow

Strong correlation:
redshifted CO outflow
redshifted optical jet

mm CO lines trace:
cold: T \sim 50 \text{ K}
slow: V_{\text{outflow}} \sim 10 \text{ km/s}

jet-driven outflow
momentum transported by outflow comparable to jet momentum.
\( P_{\text{jet}} \sim 4 \times 10^{-6} \text{ M}_\odot \text{ yr}^{-1} \text{ km s}^{-1} \)

OWENS VALLEY mm ARRAY
\( \Theta \sim 4'' \), \( Dv \sim 0.2-2.6 \text{ km/s} \)
(Mitchell et al. 1997)
FIR observations > WARM component traced by [OI]63um

[OI]63um red-shifted emission well correlated to:
- redshifted atomic jet (opt)
- redshifted CO jet (mm)

[OI]63um line trace:
- **warm**: $T_{\text{exc}} \sim 230$ K
- **intermediate Vel**: $V \sim 30-60$ km/s
A multi-wavelength study of DG Tau

**OPTICAL**
- CFHW + AO: ~ 0.1” > 14 AU
  - Dougados et al. 2000
  - Lavalle-Fouquet 2000
- HST: ~ 0.1” > 14 AU
  - Bacciotti et al. 2000, 2002
  - Maurri, Bacciotti, Podio, in prep

**NIR**
- SUBARU/IRCS: ~ 0.16” > 22 AU
  - Dv ~ 30 km/s
  - Pyo et al. 2003

**FIR**
- HERSCHEL/PACS
  - pixel ~ 9.4” > 1400 AU
  - Dv~88 km/s (at 63um)

---

Linda Podio

Goteborg, September 2010
OPTICAL observations > HOT, high-velocity, collimated atomic jet

OPTICAL [SII]6731 Å

NIR [FeII]1.64μm

JET KINEMATICS:
$V_{\text{blue}}$ up to -400 km/s

GAS PHYSICAL PROPERTIES:
dense ($n_e \sim 10^3-10^4$ cm$^{-3}$)
hot ($T_e \sim 5000-30000$ K)
highly ionized ($x_e \sim 0.1-0.8$)

JET WIDTH:
$R_{\text{blue}} \sim 25 - 170$ AU

CFHT + PUEO (~0.13”): (Dougados et al. 2000)

SUBARU/IRCS (~0.16”): (Pyo et al. 2003)
PACS observation of DG Tau: the atomic component

extended emission in ATOMIC lines!

[OI] 63um:
extended
red and blue-shifted
correlated with optical jet!
Also red lobe detected!

**VELOCITY AND RADIUS**

\[ V_{[OI]63\mu m} \approx 30-50 \text{ km/s} \ll \]
\[ V_{[OI]6300 \AA} \text{ (up to -400 km/s)} \]

\[ R_{[OI]63\mu m} \gg \]
\[ R_{[OI]6300 \AA} (1.3'\), Dougados 2000\]

**FIR [OI]63um:**
wide-angle, slow and warm outflow!

optical/NIR atomic lines
[OI]6300 ([SII], [NII], [FeII]):
fast, collimated, hot jet!
PACS observation of DG Tau: the atomic component

[CII] 158um: extended emission
no velocity information
Also RED lobe detected!

$R_{[\text{OI}]63um} >>$
$R_{[\text{OI}]6300 \text{ A}} (1.3''$, Dougados 2000)

FIR [CII]158um:
Wide-angle, warm outflow!

optical/NIR atomic lines
[OI]6300 ([SII], [NII], [FeII]): fast, collimated, hot jet!
MOLECULAR emission (high-J CO, H$_2$O, OH) detected only in the central spaxels, in the circumstellar unresolved region

p-H$_2$O 144.5 um
CO(18-17) 144.784 um
[OI] 145um
DG Tau > FIR spectrum from PACS data

<table>
<thead>
<tr>
<th>Species</th>
<th>Transition</th>
<th>$\lambda$ (\mu m)</th>
<th>$E_{upper}$ (K)</th>
<th>cont ± err (Jy)</th>
<th>Flux ± err (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[OI]</td>
<td>3P1-3P2</td>
<td>63.184</td>
<td>228</td>
<td>5.51133 ± 0.05864</td>
<td>6.30e-16 ± 5.64e-18</td>
</tr>
<tr>
<td>OI</td>
<td>3P0-3P1</td>
<td>145.525</td>
<td>326</td>
<td>8.08445 ± 0.13606</td>
<td>3.95e-17 ± 1.79e-18</td>
</tr>
<tr>
<td>[CII]</td>
<td>2P3/2-2P1/2</td>
<td>157.741</td>
<td>91</td>
<td>8.67586 ± 0.03127</td>
<td>1.06e-16 ± 2.29e-18</td>
</tr>
<tr>
<td>CO</td>
<td>J=36-35</td>
<td>72.843</td>
<td>3700</td>
<td>5.80398 ± 0.02868</td>
<td>-</td>
</tr>
<tr>
<td>CO</td>
<td>J=33-32</td>
<td>79.360</td>
<td>3092</td>
<td>6.20657 ± 0.06713</td>
<td>8.57e-18 ±</td>
</tr>
<tr>
<td>CO</td>
<td>J=29-28</td>
<td>90.163</td>
<td>2400</td>
<td>6.35590 ± 0.04193</td>
<td>1.00e-17 ±</td>
</tr>
<tr>
<td>CO</td>
<td>J=18-17</td>
<td>144.784</td>
<td>945</td>
<td>8.02271 ± 0.14646</td>
<td>3.55e-17 ± 1.98e-18</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>p 3-22 - 2-11</td>
<td>89.988</td>
<td>297</td>
<td>6.35539 ± 0.03903</td>
<td>6.64e-18 ± 3.46e-18</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>p 4-13 - 3-22</td>
<td>144.518</td>
<td>396</td>
<td>8.60150 ± 0.16805</td>
<td>-</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>p 3-31 - 4-04</td>
<td>158.309</td>
<td>410</td>
<td>9.57034 ± 0.28915</td>
<td>-</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>o 4-23 - 3-12</td>
<td>78.741</td>
<td>432</td>
<td>6.14538 ± 0.05279</td>
<td>7.91e-18 ± 4.65e-18</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>o 2-12 - 1-01</td>
<td>179.527</td>
<td>115</td>
<td>9.02602 ± 0.04593</td>
<td>1.12e-17 ± 2.16e-18</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>o 2-21 - 2-12</td>
<td>180.488</td>
<td>194</td>
<td>8.69165 ± 0.05328</td>
<td>7.01e-18 ± 2.52e-18</td>
</tr>
</tbody>
</table>
A multi-wavelength study of T Tau

(Solf & Mundt 1999)
ISO observation of T Tau: atomic/molecular lines

atomic/molecular lines !!!

no spatial information

no velocity info

Spinoglio et al. 2000
PACS observation of T Tau: the atomic component

extended emission in ATOMIC lines

[OI] 63um: extended velocity shifted emission
PACS observation of T Tau: the atomic component

extended emission in ATOMIC lines

[CII] 158 um
PACS observation of DG Tau: the molecular component

T Tau OI_145

Extended emission in MOLECULAR lines

p-H$_2$O 144.518 um
CO(18-17) 144.784 um
[OI] 145.525 um
PACS observation of T Tau: the molecular component

Extended emission in molecular lines

o-H$_2$O 179.527 um
o-H$_2$O 180.488 um
[OI] 63 um: MASS LOSS tracer

In a dissociative J-shock if [OI] emission is optically thin ($n_0 V_{\text{shock}} < 10^7 \text{ km s}^{-1} \text{ cm}^{-3}$)

\[
\dot{M}_* = 10^{-6} \left[ \frac{L(\text{OI} 63 \mu\text{m})}{10^{-2} L_\odot} \right] (\text{yr}^{-1})
\]

Hollenbach & McKee 1989

<table>
<thead>
<tr>
<th>Source</th>
<th>$\dot{M}_{\text{jet}} ([\text{OI}]6300 \text{ Å})$</th>
<th>$\dot{M}_{\text{jet}} ([\text{OI}]63 \mu\text{m})$</th>
<th>$\dot{M}_{\text{acc}}$</th>
<th>$\dot{M}<em>{\text{jet}}/\dot{M}</em>{\text{acc}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG Tau</td>
<td>$3 \times 10^{-7}$ \textsuperscript{a}</td>
<td>$1.5 \times 10^{-7}$</td>
<td>$2 \times 10^{-6}$ \textsuperscript{a}</td>
<td>$0.07 - 0.15$</td>
</tr>
<tr>
<td>T Tau</td>
<td>$5.0 \times 10^{-7}$</td>
<td>$3 - 5 \times 10^{-8}$ \textsuperscript{b}</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} from Hartigan et al. 1995

\textsuperscript{b} from Calvet et al. 2004 for T Tau N

Ceccarelli et al. 1997
Outline:

Introduction: accretion/ejection process in YSO
  role of stellar jets in the star formation process
  theoretical models for jet launch
  jets observational properties
  Multi-\lambda studies: importance & problems

First results from GASPS/PACS data:

FIR maps of outflow from Class II sources (DG Tau B, DG Tau, RW Aur, T Tau, RY Tau, ...)
  Extended, velocity-shifted emission in atomic and/or molecular lines
  Estimate of mass flux rate > mass ejection/mass accretion

Open issues:
  Desentangling jet/disk emission in the central spaxel
  OI63-cont in jet and non-jet sources
  Line ratios
  HIFI observations > velocity resolved line profiles
In the unresolved circumstellar region (central spaxel)
Can we distinguish between JET and DISK emission ???
COMPARISON JET, NON-JET SOURCES

Howard, Sandell et al., in prep

Jet sources

Non-Jet sources

Howard, Sandell et al., in prep
From the analysis of 500 ISO observations of outflows from YSO:

\[ 1 < [\text{OI}]_{63}/145 < 30 \]
\[ 0.1 < [\text{OI}]_{63\mu m}/[\text{CII}]_{158} < 20 \]

Subset of the DENT grid of models (Woitke et al. 2009, Kamp et al. 2010, Pinte et al. 2010) which reproduce the observed [OI]63\(\mu m\) fluxes (4-90 \(10^{-18}\) W/m\(^2\)).

Thi et al. 2010; RECX 15: Woitke et al. (in prep.). Outflow sources are shown in red (Liseau et al. 2006, lines indicate contour containing 90% of points, hash indicates 68% of points). Gray regions indicate 99, 90, and 68% of DENT models with [OI] 63 flux consistent with our observations (4–90 \(\times 10^{-18}\) W/m\(^2\) at 140 pc).
HIFI OBSERVATION > LINE VELOCITY PROFILES

OT1 proposal for HIFI follow-up observations

<table>
<thead>
<tr>
<th>Source</th>
<th>D(pc)</th>
<th>$M_*$ (M$_\odot$)</th>
<th>PA$_{jet}$</th>
<th>mm</th>
<th>NIR</th>
<th>opt</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG Tau A</td>
<td>140</td>
<td>0.67</td>
<td>226°</td>
<td>-</td>
<td>Pyo et al. 2003</td>
<td>Bacciotti et al. 2000</td>
</tr>
<tr>
<td>T Tau</td>
<td>140</td>
<td>2.2 / 0.6</td>
<td>0°, 90°</td>
<td>Edwards &amp; Snell 1982</td>
<td>Herbst et al. 2007</td>
<td>Solf et al. 1999</td>
</tr>
<tr>
<td>HD 163296</td>
<td>122</td>
<td>2.3</td>
<td>223°</td>
<td>-</td>
<td>Benisty et al. 2010</td>
<td>Grady et al. 2000</td>
</tr>
<tr>
<td>AB Aur</td>
<td>144</td>
<td>2.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Grady et al. 1999</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>$\nu$ (GHz)</th>
<th>$\lambda$ (µm)</th>
<th>trans</th>
<th>Obs Mode</th>
<th>beam (&quot;)</th>
<th>$\Delta V$ (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[CII]</td>
<td>1900.5</td>
<td>157.741</td>
<td>2P3/2-2P1/2</td>
<td>HMap DBS</td>
<td>13</td>
<td>0.2</td>
</tr>
<tr>
<td>CO</td>
<td>1152.0</td>
<td>260.2</td>
<td>J=10-9</td>
<td>HMap DBS</td>
<td>19</td>
<td>0.3</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>556.9</td>
<td>538.3</td>
<td>ortho 1$_{10-101}$</td>
<td>HPoint DBS</td>
<td>39</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Some data reduction issues...

- **PSF:** ~10” up to 120 um  
  >10” for λ >120um

  **POINT SOURCE:** From reconstructed PSF at every λ > aperture correction to obtain correct flux

  **EXTENDED SOURCE:** flux in the outer pixel may be contaminated by emission on the central spaxel. If there is extended emission the flux in the outer spaxels is >> then PSF contribution

- **VELOCITY SHIFTS** may be caused by uneven slit illumination

- **COMPUTATION OF LINE RATIOS** on each spaxel

  May be an issue because the emission in every spaxel is contaminated by the emission on the surrounding spaxels

  DECONVOLUTION?