First unbiased millimeter survey of a protostellar outflow : Peering into Cep E

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I. Introduction

Protostellar outflows play a crucial role in molecular cloud evolution and star formation, by transferring momentum and energy back to the ambient medium. In the early protostellar stages, fast jets powered by the nascent star, possibly surrounded by a wider angle wind, are seen to interact with the parental medium through molecular bowshocks, producing a slower moving molecular outflow "cavity". Fast and well-collimated molecular "bullets", tracing internal shocks within the jet, are also seen in many cases. However, the launch process of jets, the importance of wide-angle winds, and the feedback of outflow shocks on cloud chemistry and turbulence, all remain major enigmas in star formation research.

The basic dynamics of protostellar shocks has been modelled successfully by several authors but the actual chemical composition of molecular bowshocks is still badly known. In particular, it is crucial to determine the nature of the shock accelerating the outflow, either purely hydrodynamical or a continuous, non-dissociative(« C-type ») shock with a magnetic precursor where ions are decoupled from the neutral fluid. C-type shocks are predicted to play an important role in the gas chemical evolution through the temperature and density changes resulting from the activation of endothermic reactions, ionization, and dust sputtering in the ion-neutral drift zones. These various processes lead to abundance enhancements up to several orders of magnitude, as reported for various molecular species in "chemically active" outflows such as L1157 (Codella et al. this conference, 2010; Lefloch et al. 2010; Bachiller et al. 2001). There is now direct evidence that outflows can contribute to the chemical enrichment of the interstellar gas as complex molecules are formed in bowshock regions (Codella et al. 2009).

To address these issues, we have started an unbiased survey of the millimeter line emission of the Cep E intermediate-mass protostellar outflow. It is one of the very few outflows where bright emission is detected both in the entrained gas and in the powering jet and its proper motions are. We present and discuss the first results of the survey, in particular the present census of the chemical composition in the shocked gas and in the driving jet.

II. Observations

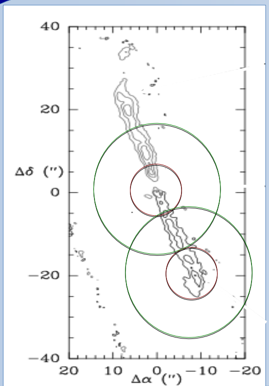


Figure 1: Map of the CO 2-1 emission at 1" resolution obtained with the PdBI. The red circles represent the IRAM beam at 1mm and the green circles at 3mm.

The observations of the 1.3 mm and 3 mm bands towards Cep E were carried out at the IRAM 30m telescope, in March and July 2010. We used the WILMA autocorrelator as spectrometer, which provided a spectral resolution of 2 MHz (~2 km/s at 1.3 mm and 6 km/s at 3mm).

We targeted the central protostellar source and the apex of the south outflow lobe at offset position (-12, -18). Observations were carried out in Wobbler-Swithing mode, adopting a throw of 4 arcmin and a phase time of 2 sec.

We covered the bands [80, 116] GHz, [210, 236] GHz and [264, 269] GHz.

The data were reduced and analysed using the CLASS software. Line identification was performed using WEEDS (Maret, Hily-Blant, Pety et al., in prep. 2010).

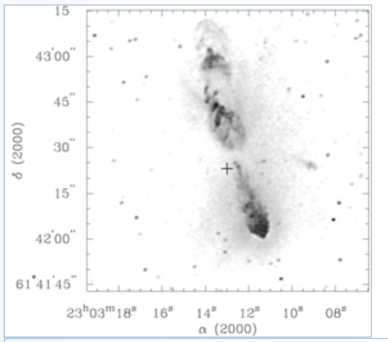


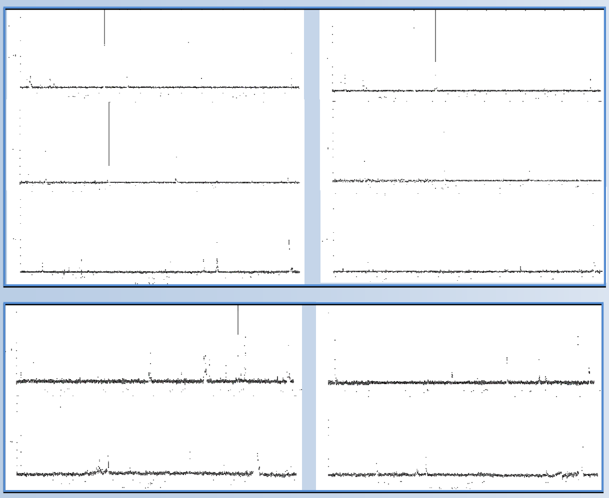
Figure 2: Image of the H_2 2.12 μm line. The position of the submillimeter continuum source is marked by a cross. (Ladd & Hodapp 1997) .

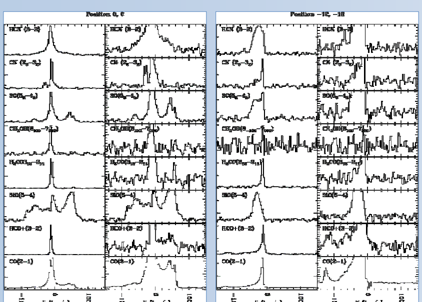
III. Results

(0, 0) (-12,-18)

3mm

1mm





We have observed three components:

- the **ambient gas**, detected in both positions, at ~11 km/s;
- the **entrained gas**, detected in both positions, at (-90 → -12) and (-9 → +40)
- the **jet**, detected at -125 km/s in the south lobe and at +50 km/s in the north lobe

	offset:(0,0)			offset:(-12,_18)		
	ambient gas	entrained gas	Jet	ambient gas	entrained gas	Jet
CO	x	x		x	x	x
CS	x	x	x	x		
HCN	x	x		x	x	
DCO+	x			x		
HCO+	x	x	x	x	x	x
D2CO	x					
H2CO	x	x		x	x	
SO2	x	x		x	x	
SiO	x	x		x	x	
SO	x	x				
HDCO	x					
CH3OH	x			x	x	
CH3CHDCN	x					
HCOCN	x					
HNCO	x					
H2CS	x			x		
CCD	x					
CN	x	x		x	x	
DCN	x					
N2D+	x					
N2H+	x			x		
C2H3CN	x					
HCCN	x					
NH2D	x					
CH3CCH	x			x		
CH3CN	x					
HC3N	x			x		
OCS	x					
CCS	x					
HNC	x			x		
CCH	x					

Table 1: List of species detected towards the central position (0,0) and the position of the sout lobe (-12'',-18''), in the three different components.

Figure 4: Zoom on sample spectra of species detected towards the central position and the south lobe (see Table 1). The spectra show the different velocity components: the ambient gas, the entrained gas and the jet.

IV. Conclusions

Cep E is a chemically active outflow, similar to L1157 (Bachiller et al. 2001). We observe a different chemical composition in the three components: ambient gas, entrained gas and jet. Typical hot core species are detected towards the protostellar source and typical shock tracers are observed towards the jet. The entrained gas shows some characteristics of both.

Next steps:

- Complete the survey in the whole millimeter bands accessible from IRAM, at 1km/s of resolution.
- Once the survey is completed, determine the chemical abundances in the three components.
- Search for complex molecules in the shocks.
- Physical conditions in the shocks will be investigated with Herschel SPIRE and HIFI from observations of the H_2O and high-J CO lines.

References

Bachiller et al. Astronomy and Astrophysics, Vol. 372, p.899-912 (2001)

Codella et al. Astronomy and Astrophysics, Vol 507, Issue 2, 2009, pp.L25-L28

Maret, Hily-Blant, Pety et al., in prep. 2010

Lefloch et al. Astronomy and Astrophysics, Vol 518, 2010 id.L113