

COMPARISON OF CHEMICAL AND TRADITIONAL TEMPORAL INDICATORS

SILVANA NIKOLIĆ

Onsala Space Observatory, 439 92 Onsala, Sweden

Astronomical Observatory, Volgina 7, 11160 Belgrade-74, Serbia, Yugoslavia

E-mail silvana@oso.chalmers.se

Abstract. L1251 is an active low-mass star forming cold dark cloud at the edge of the Cepheus molecular cloud complex. Among seven embedded IR sources in L 1251, two are believed to power two detected CO outflows: IRAS 22376+7455 and IRAS 2343+7501. We have observed these cores with the Onsala Space Observatory 20-m telescope, sampling a region of about 30 000 AU around the embedded sources. LTE-derived column densities of several rare isotopic molecules have enabled us to calculate relative abundances of CS, HCO⁺, SO and HNC. This "chemical diagnostics" of age is compared with one of the traditional temporal indicators, the size and time scale of the outflow.

1. INTRODUCTION

Chemistry in dark clouds and cold molecular cores changes during the star formation processes: prior to star formation, chemistry is dominated by low-temperature gas-phase reactions and grain surface reactions. As soon as the new star starts to warm the surroundings, the ices are heated and molecules evaporate back to gas phase. Furthermore, shocks from protostellar outflows can change the environment significantly. While the abundances of some molecules (e.g. SiO, HCN, SO) are found to be larger by an order of magnitude along the axis of the outflow, the chemical composition of a dense core around the protostar may not change significantly (Bachiller & Pérez Guitérrez 1997). Therefore, chemical evolution of such dense cores can be described with gas-grain chemical models (e.g. Bergin & Langer 1997) or even pure gas-phase models, without need to incorporate shock-chemistry. In gas-phase models, for example, molecules whose production is linked to the carbon network, e.g. CN, HCN and CS, have larger abundances at early ($\sim 10^5$ yrs) times; other molecules, e.g. SO, who are independent or destructively linked to the carbon chemistry, should have larger abundances at late times ($\sim 10^8$ yrs), when equilibrium is reached (van Dishoeck & Hogerheijde 1999).

The L1251 dark cloud (Lynds 1962), located at the edge of the Cepheus molecular cloud complex, is an active low mass star formation site with at least seven IRAS point sources classified as embedded objects (Kun & Prusti 1993). Embedded sources IRAS 22376+7455 and IRAS 2343+7501 are suggested to be powering two detected outflows (Sato *et al.* 1994). These CO outflows have different morphology indicating

different ages: the IRAS 22376+7455 outflow is compact and highly collimated and has an estimated dynamical timescale of 2×10^4 yrs, while the IRAS 22343+7501 outflow is extended with the dynamical timescale estimated to be $\sim 1 \times 10^5$ yrs.

2. What did we do and why

We present here first results of our multiwavelength study of L1251: using the 20-m telescope of the Onsala Space Observatory we have mapped the previously detected dense cores (NH₃, Tóth & Walmsley 1996) in the CS (2–1), HCO⁺ (1–0), HCN (1–0) and HNC (1–0) lines. The estimated distance to L1251 is 300 pc (Kun & Prusti 1993). At that distance the spatial resolution achieved with the Onsala 20-m telescope is about 15 000 AU. The cores are in all molecular lines mapped of about the same size. Assuming spherical or elliptical shape, the 50% integrated intensity contour levels of the cores have diameters of about 20–35 000 AU.

Table 1. LTE-derived total column densities

Molecule	IRAS 22376+7455 ¹⁾ N [cm ⁻²]	IRAS 22343+7501 ²⁾ N [cm ⁻²]
¹³ CO	1.43×10^{16}	1.20×10^{16}
C ¹⁸ O	3.07×10^{15}	2.36×10^{15}
C ³⁴ S	2.19×10^{12}	0.97×10^{12}
H ¹³ CO ⁺	1.21×10^{12}	0.99×10^{12}
HC ¹⁸ O ⁺	$< 0.1 \times 10^{12}$	
HN ¹³ C	1.52×10^{12}	0.63×10^{12}
H ¹⁵ NC	$\sim 0.4 \times 10^{12}$	$< 0.2 \times 10^{12}$
SO	1.48×10^{13}	0.67×10^{13}
CH ₃ CCH	1.50×10^{14}	1.64×10^{14}

¹⁾ $T_{\text{ex}} = 30$ K for all molecules with exception of CO isotopes where $T_{\text{ex}} = 10$ K.

²⁾ $T_{\text{ex}} = 20$ K for all molecules with exception of CO isotopes where $T_{\text{ex}} = 10$ K.

CO (Sato *et al.* 1994) and ammonia (Tóth & Walmsley 1996) data indicated uniformly cold gas ($T_K \sim 10$ K) across the cloud. However, our CH₃CCH observations indicate slightly higher excitation temperatures for the two cores associated with outflows, ~ 30 K for IRAS 22376+7455 and ~ 20 K for IRAS 22343+7501. The remaining cores in the cloud show temperatures less than 15 K as determined from the CH₃CCH data. Discrepancy in kinetic temperature determinations from different molecules may indicate that methyl acetylene (propyne) probes regions deeper inside a core, while CO probes outer envelopes of molecular cloud cores. If this is true, then the different kinetic temperatures obtained may indicate that in the IRAS 22343+7501 case a longer time interval has elapsed since the brief outflow's shock heating of the surrounding gas (Bergin *et al.* 1998)

We have also observed SO and a number of less common isotopes of the molecules used for the mapping to allow more reliable abundance calculations. Main isotope molecules often show that strong saturation effects are present and are thus not useful for abundance estimates. This is a general trend in both cores. Total column densities, derived assuming LTE conditions, are listed in Table 1.

In Table 2 we give the corresponding fractional abundances, $N_{\text{mol}}/N_{\text{H}_2}$, of the main isotopes. The H_2 column density was determined using the conversion factor from the carbon-monoxide and the molecular hydrogen column densities of $[\text{H}_2]/[^{13}\text{CO}]=4.8\times 10^5$ (Dickman & Clemens 1983). With the exception of SO and CH_3CCH , the fractional abundances were derived from rarer isotopes by multiplying with the corresponding isotopic elemental abundance ratios ($^{12}\text{C}/^{13}\text{C}\sim 60$, $^{32}\text{S}/^{34}\text{S}\sim 23$). We have also included data from Bachiller & Pérez Gutiérrez (1997) of an IRAS source associated with a compact outflow in L1157 (Lynds 1962). Their fractional abundances have been recalculated using the isotopic abundance ratios indicated above.

Table 2. Abundances relative to H_2

Molecule	IRAS 22376+7455 ¹⁾	IRAS 22343+7501 ¹⁾	IRAS 20386+6751 ²⁾
CS	7.3×10^{-9}	3.8×10^{-9}	6.4×10^{-9}
HCO^+	1.0×10^{-8}	1.0×10^{-8}	3.8×10^{-8}
HNC	1.3×10^{-8}	0.6×10^{-8}	0.3×10^{-8}
SO	2.2×10^{-9}	1.2×10^{-9}	8.0×10^{-9}
CH_3CCH	2.2×10^{-8}	2.8×10^{-8}	-

¹⁾ L1251 data: according to the morphologies of the outflows, IRAS 22376+7455 could be a class 0 protostar, and IRAS 22343+7501 a class I protostar.

²⁾ L1157 data: a powering source of a compact outflow, IRAS 20386+6751, classified as a class 0 protostar (Bachiller & Pérez Gutiérrez 1997).

3. A view

The fractional abundances variations we see can not be for sure attributed to chemical evolution. This applies to the gas within about 5 - 10 000 AU from the central objects. As indicated by the difference in the estimated dynamical ages of the outflows powered by their embedded IR sources, ages of these two cores may differ by about 10^5 years. In the two cores in L1251 the fractional abundances of HCO^+ and CH_3CCH are very similar. CS, SO and HNC are all lower by a factor of 2 in IRAS 22343+7501 relative to IRAS 22376+7455, thus keeping the SO/CS abundance ratio constant. This ratio is expected to be low at 'early times' and high at 'late times', as demonstrated by time-dependent chemical models (e.g. Bergin & Langer 1997). However, relative abundances of CS and HNC follow those predicted by chemical models, i.e. higher

relative abundances are expected in "younger" cores. There are a number of reasons that might explain our results, e.g.:

- ◊ the drastic changes of the SO/CS abundance ratio only apply to the very dense parts of the cores, beyond the Onsala 20-m telescope spatial resolution
- ◊ uncertainties in the sulfur chemistry in cold dark clouds, coupled with the oxygen chemistry
- ◊ the physical ages of the cores studied are not within the relatively short time interval when significant changes of the SO/CS abundance ratio occur and
- ◊ the estimated dynamical ages of the outflows are crude, since the morphology of the outflows partly depends on the ambient ISM. Thus the sample cores may actually be of similar ages.

IRAS 20386+6751 in L1157 powers a compact outflow; so far the best studied outflow from a chemical point of view (Bachiller & Pérez Gutiérrez 1997). Since the IRAS 22376+7455 outflow in L1251 is also compact, the ages of the two sources may be similar. However, the comparison of fractional abundances in these two cores is not straightforward. The dark clouds L1157 and L1251 are not in the same region of the sky, implying that initial elemental abundances and physical environments are not necessarily the same. Thus different fractional abundances may be expected.

4. One sentence for the end

As seen above, there is still a long way to go before uncertainties in chemical networks as well as input parameters in more "traditional" temporal indicators, are cleared.

Acknowledgements

Valuable comments and suggestions received from Dr. L.E.B. Johansson (Onsala Space Observatory, Sweden) and Dr. Jorma Harju (University Observatory, Helsinki, Finland) are greatly appreciated.

References

- Bachiller, R. and Pérez Gutiérrez, M.: 1997, *Astrophys. J.*, **487**, L93.
 Bergin, E.A. and Langer, W.D.: 1997, *Astrophys. J.*, **486**, 316.
 Bergin, E.A., Melnick, G.J., Neufeld, D.A.: 1998, *Astrophys. J.*, **499**, 777.
 Dickman, R.L. and Clemens, D.P.: 1983, *Astrophys. J.*, **271**, 143.
 Lynds, B.T.: 1962, *Astrophys. J. Suppl.*, **7**, 1.
 Kun, M. and Prusti T.: 1993, *Astron. Astrophys.*, **272**, 235.
 Sato, F., Mizuno, A., Nagahama, T. *et al.*: 1994, *Astrophys. J.*, **435**, 279.
 Tóth, L.V. and Walmsley C.M.: 1996, *Astron. Astrophys.*, **311**, 981.
 van Dishoeck, E.F. and Hogerheijde, M.R.: 1999, *The Physics of Star Formation and Early Stellar Evolution II* eds. C.J. Lada and D. Kylafis, Dordrecht: Kluwer.