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Shocks and PDRs in an intermediate mass star forming globule: the case of IC1396N

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Abstract. The dark globule IC1396N is a typical example of a star formation process induced by radiation driven implosion due to the strong UV field from a nearby O6 star. The IRAS source embedded in the globule and its associated molecular outflow have been observed with the Long Wavelength Spectrometer (LWS) on ISO revealing an extremely rich spectrum including: CO rotational lines from J=14-13 up to J=28-27, rotational lines from ortho-H_2O, OH lines involving the first four rotational levels of both ladders, atomic ([OI]63μm, [OI]145μm) and ionic ([CII]157μm, [OIII]52μm, [OIII]88μm) lines.

A complex picture arises, where an externally illuminated PDR coexists with strong C-shocks within IC1396N and whose origin is not clear.

1. Introduction

IC1396 is an extended HII region located in Cepheus and excited by the O6 star HD206267; it is part of the more complex Cep OB 2 association located at a distance of 750 parsec (Becker & Fenkart 1971) from the Sun.

Many bright rimmed globules have been discovered within the IC1396 HII region, traced by the optically visible ionization front in the direction of the O6 star, and some of them are associated with embedded IRAS sources indicating a presumably recent and ongoing event of externally induced star formation. IC1396N is located 16 parsecs NNE of HD 206267 and is associated with the brightest of these IRAS sources, IRAS21391+5802 ($L_{\rm bol} \sim 230 L_\odot$), which is a typical Class I associated with a CO bipolar outflow (Sugitani et al. 1989). We discuss the properties of the circumstellar environment of this source as deduced from observations obtained with the Long Wavelength Spectrometer

(LWS, Clegg et al. 1996) on board of the Infrared Space Observatory (ISO, Kessler et al. 1996).

2. Observations and Results

LWS spectra of the IC1396N globule were taken during orbit 96 (26/02/96); three pointings were performed (ON source + West outflow lobe , East outflow lobe, empty reference position - see Fig. 1 in Saraceno et al. 1996); the continuum-subtracted ON-source spectrum is shown in Fig. 1.

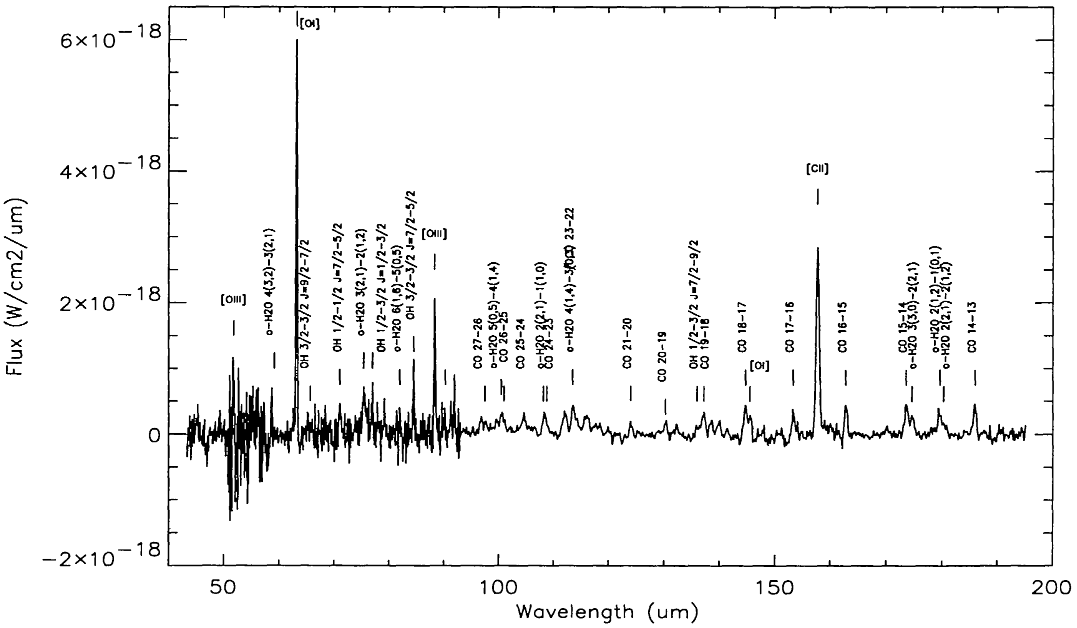

Figure 1. Spectrum of IC1396N ON-source (α(1950) 21:39:10.3 δ(1950) +58:02:29); low degree polynomial baselines have been subtracted from each detector spectrum, and the ten mini spectra have been merged.

Preliminary results from these observations have already been presented by Saraceno et al. (1996) where further details about observations are given. In the present work we present a more accurate analisys based on the LWS Off-Line Processing (OLP) Version 6, with greatly improved responsivity drifts correction and more reliable technique to reference to Uranus (the primary calibrator). The repeatability of grating scan data has greatly improved, along with a much better agreement between spectra taken by adjacent detectors.

3. Discussion

3.1. Atomic lines: PDRs *vs* J-shocks

Atomic and ionic ([OI]63μm and 145μm, [CII]158μm) lines are detected at each of the three observed positions. Several authors suggest that line ratios can be used to discriminate between PDR (Wolfire et al. 1990) or J-shock (Hollenbach

& McKee 1989) excitation, which are generally responsible for [OI] and [CII] emission. However on none of the observed positions the detected lines can be simply ascribed to any of the two mechanisms, the [OI]63/[OI]145 ratio being too small. This effect is also seen on all the YSOs observed with LWS and can be ascribed to [OI]63μm self-absorption (Saraceno et al. this volume). If [OI] and [CII] lines are excited by the same mechanism the [OI]63μm/[CII]158μm ratio would be better explained in terms of PDR emission (Wolfire et al. 1990). The detection of [CII]158μm at each of the observed positions (with line flux variations less than 40%) strongly suggests (Wolfire et al. 1990) that emission is originated in a diffuse PDR of density $10^3 < n < 10^5$ cm^{-3} and illuminated by a relatively faint UV field with G_o of the order of few tens, compatible with the O6 star HD 206267 being the illuminating source (by the way, the latter source is also responsible for the [OIII] lines detected at each of the three observed positions); with the above n and G_o values the [OI]63μm line is expected to be less intense than actually observed, possibly suggesting that J-shocks may give the dominant contribution to [OI] emission.

3.2. Molecular lines: C-shocks

The spectrum of Fig.1 reveals plenty of molecular lines: CO rotational lines from J=14-13 up to J=28-27, 10 rotational lines from ortho-H_2O and OH lines involving the first four rotational levels of both ladders. A best-fit LVG model (Nisini et al. this volume) was first obtained for CO lines with a temperature of 1600K (equivalent to a shock velocity of 25 km/s), a gas density $n_{H_2}=10^5$cm^{-3} and optically thin CO lines. We then applied the same model to the o-H_2O lines keeping T and n_{H_2} fixed as determined from CO, assuming that the emitting region for the two species is the same; water lines turned out to be optically thick so that the water column density N_{o-H_2O} and the size θ of emitting region were adjusted to fit o-H_2O line ratios and absolute fluxes respectively, providing $N_{o-H_2O}=10^{17}$ and $\theta=7''$. Assuming a CO/H_2 abundance $X_{CO}=10^{-4}$ then implies $X_{o-H_2O}=4\cdot10^{-5}$. The physical mechanism heating the gas to temperature of 1600K cannot be related to the ionizing O6 star because it has not enough power to significantly heat the gas at the position of IC1396N (16 parsecs away). Furthermore molecular emission is only seen ON-source; we also have marginal detections for few molecular lines in the two OFF-source positions but they are compatible with ON-source emission entering into the beam. Hence the heating mechanism is intrinsic to IC1396 N itself and in the following we briefly examine various possibilities.

Direct heating from the 200 $L_\odot$ embedded source can be ruled out because molecular lines are seen to arise from a $\theta \sim 7''$ region (corresponding to 5000AU) at a temperature of 1600K while at radial distances $\sim \theta/2$ from the center the temperature is only $\sim$ 32K (Saraceno et al. 1996; we assume $T_{gas} \sim T_{dust}$, see Ceccarelli et al. 1996). The fact that molecular lines are the main gas coolants in IC1396 N, the CO+H_2O+OH cooling rate being 0.9$L_\odot$ and more than twice the [OI] cooling rate, allows us to conclude that a PDR excitation cannot explain molecular emission (Nisini et al. this volume); the same argument is against a J-shock interpretation, the observed molecular abundance being also difficult to reconcile with these fast ($v \geq$50 km/s) and dissociative shocks. C-shocks (Draine 1980; Kaufman & Neufeld 1996) seem ideal candidates to explain the observed molecular emission where water and CO lines, together with NIR H_2 vibrational lines, are indeed expected to be major gas coolants. Unfortunately we soon run into problems because the observed H_2O/CO cooling ratio (~ 0.3) is incompatible with the value (~ 5) deduced, using Kaufman & Neufeld's models, for a temperature of 1600K (as derived from CO line fitting, see above). Despite this inconsistency, which probably requires us to revisit some critical assumptions on which C-shocks models are based, we think that C-shocks are the most reasonable candidates to explain the copious molecular emission observed on IC1396 N on-Source. The total power radiated by a shock can be written as $L_{Sh} \sim 1/2\cdot\, v_s^3 \rho_s A_{\rm eff}$, where v_s and ρ_s are the shock velocity and density and is the shock effective area, and for the shock parameters derived above provides $L_{Sh} \sim 4L_\odot$ which is comparable to the total CO+H_2O+OH observed cooling rate plus an estimated contribution of $0.9L_\odot$ (Nisini et al. this volume) from H_2 cooling; hence we may conclude that the observed shock is essentially cooling via molecular lines in the infrared.

But what is the physical mechanism responsible for the shock? Shocks are produced at the interface where the wind accelerates the outflow and it is predicted (e.g. Davis & Eislöffel 1995) that the luminosity radiated in lines should be comparable to the outflow kinetic luminosity; in the case of IC1396 N the outflow luminosity (Sugitani et al. 1989) is only $0.02L_\odot$, about 40 times lower than the power radiated by the shock via FIR CO and H_2O lines. An incorrect estimate of the outflow kinetic luminosity (a possibility claimed by Davis & Eislöffel to explain similar results they obtained in few cases) seems unlikely in this case because the outflow lobes appear to be partially superposed (Sugitani et al. 1989), and the measured velocities can then be considered as good estimates of the real gas velocity; alternatively the momentum may not be conserved in the wind-outflow interaction.

The possibility that the observed shock emission is arising from infall motions is only tentatively suggested here and a detailed analysis in this sense is postponed to a forthcoming paper.

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