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ISO-LWS observations of IRAS16293-2422

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Abstract

We obtained LWS grating spectra toward IRAS 16293-2422 and the surrounding region, which covers the entire extent of the molecular outflow. The LWS spectra show that the region is relatively uncontaminated by PhotoDissociationRegion (PDR)-like emission, showing only a weak diffuse CII emission. The on-source spectrum revealed the presence of the OI(63μm) line and several lines from CO, H_2O and OH molecules. In this work we derive the macroscopic quantities associated with the UV-illuminated emitting gas which surrounds IRAS16293-2422 and compare it with previous studies. We show that the molecular lines originate in a hot (~1600 K), dense ($\sim 3 \cdot 10^4 cm^{-3}$) and extended ($\sim 8 \cdot 10^{16}$cm) region, that we interprete as the shock of the wind impacting obliquely with the walls of the cavity created by the wind itself. The OI(63μm) line observed by the Kuiper Airborne Observatory (KAO: Ceccarelli et al. 1997a) at $\sim 1.2 \cdot 10^{17}$cm west from the central source is hence interpreted as the head of the shock where the wind strikes the ambient gas. Finally we speculate that the OI(63μm) line emission seen on-source originates in the collapsing envelope that surrounds the central object(s).

1. Introduction

IRAS16293-2422 is one of the best studied and interesting Young Stellar Objects (YSO), in which infall has been claimed to occur simultaneously with outflow (Zhou 1995). It lies in a fairly isolated and cold molecular cloud core in the rho Ophiuchus complex at a distance of 160pc. The core shows two clumps of material separated by about 2' (Wootten & Loren 1987; Mizuno et al 1990). The second clump is centered on the 27$L_\odot$ source IRAS16293-2422, but is so cold and obscured that no emission is detected at wavelengths shorter than 12μm, making it one of the coldest YSOs yet known, the so-called Class 0 objects (André et al. 1993, Saraceno et al. 1996). Radio and millimeter interferometric observations have shown that this IRAS source is actually a binary system, whose two components, 1629a (southeast, 0.6Mo) and 1629b (northeast,0.9Mo), are 800A.U. apart (Wootten 1989; Mundy et al. 1992; Walker et al 1993), embedded in an extended 4.5Mo dusty envelope (40"to 35") at 20K. A "peculiar" outflow toward IRAS16293-2422 was independently discovered by Walker et al (1985), Fukui et al (1986), and Wootten & Loren (1987). Observations of the CO(J=2→1) transition with higher spatial resolution have shown that this outflow has a quadrupole shape (Walker et al 1988; Mizuno et al 1990), now interpreted as two separated, almost perpendicular outflows emanating from 1629a and 1629b, respectively (Walker et al 1993). Ceccarelli et al. (1997a) mapped the outflow in the OI(63μm) line. From the total observed OI(63μm) line flux, they derived a mass loss rate of ($2 \cdot 10^{-6} M_\odot yr^{-1}$) about 4 times lower than that inferred by the CO measurements, implying probably an outflow dynamical lifetime a factor 4 higher than usually assumed, i.e. $2 \cdot 10^4$yr.

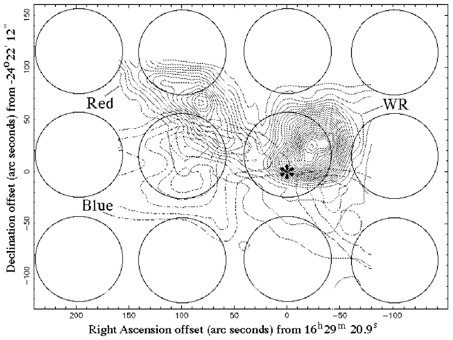

Fig. 1.— Map of the ISO-LWS observations

2. Observations and results

During Revolution 85 (10th February 1996), we obtained LWS grating spectra from 43μm to 197μm toward the region of IRAS 16293-2422. The observations consist of a 400"x300"map centered at RA = $16^h29^m24^s\!.6$, $\delta = -24°22'03''$, and, a deep integration on-source centered at RA = $16^h29^m20^s\!.9$, $\delta = -24°22'13''$. The map is formed by 4(RA)x3(δ) positions separated 100". At each position 4 grating scans were taken with 0.25sec integration ramps at each commanded grating position and the spectra were oversampled at 1/4 of a resolution element. The total on target time to get the entire map amounted to 2509sec. The positions of the map are shown in Figure 1, superimposed to the CO:4-3 map of the outflow (White 1996).

We also obtained 16 grating scans taken with 0.50sec integration ramps, over-sampled by a factor 4 with respect to the spectral resolution, toward the source,

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1997IAUS..182P..66C

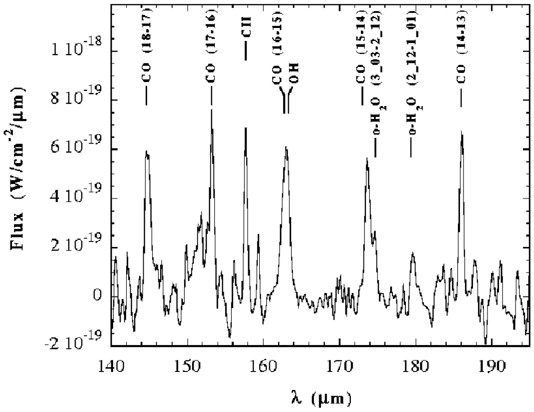

Fig. 2.— On-source line spectrum

totaling another 2509sec of on target time. All the spectra were calibrated by using the Uranus spectra (Swinyard et al. 1996) and the relative accuracy is estimated to be better than 30%. Finally, the LWS beam is roughly fixed and equal to 80" (Swinyard et al. 1996).

The map spectra revealed CII(157μm) line emission at all positions, with an average flux equal to $2 \cdot 10^{-19}$W cm^{-2}. The OI(63μm) line was only detected on-source ($6.5 \cdot 10^{-19}$W cm^{-2}) and results less than $\sim 3 \cdot 10^{-19}$W cm^{-2} in the other positions of the map. The more sensitive observations on-source revealed several molecular lines, as showed in Figure 2 after continuum subtraction.

3. Discussion

3.1. The diffuse CII(157μm) line emission

CII(157μm) line emission was detected at a similar level at all observed positions, with no evidence of any gradient or dishomogeneity, within the calibration uncertainty. The intensity we derive, $1.5 \cdot 10^{-5}$erg sec^{-1} cm^{-2} sr^{-1}, is compatible with the flux reported by Yui et al (1993), who measured an upper limit of $2 \cdot 10^{-5}$erg sec^{-1} cm^{-2} sr^{-1} with a 12'.4 beam.

Thanks to the observed homogeneity, the interpretation on the origin of the CII(157μm) line emission is straigthforward: it comes from the UV illuminated PDR (Tielens & Hollenbach 1985) gas belonging to the cloud, and is not directly associated with IRAS16293-2422. Taking a cloud density of $2 \cdot 10^3$cm^{-3} (Walker et al. 1990) and applying the model results by Wolfire et al (1990), for a beam filling factor equal to one, the observed CII(157μm) intensity requires of a weak incident UV field, correspondig to $G_o \leq 1$ (i.e. less than the local average interstellar UV flux). The computed OI(63μm) flux associated with this PDR emission would thus be less than 1/50 of the CII(157μm) (observed) flux and hence undetectable by these observations. Finally, the CI(610μm) line observed toward IRAS16293-2422 (Walker et al 1993; White et al 1997) can now be interpreted as originated by the UV illuminated gas. Infact the model of a slab with a density of $2 \cdot 10^3$cm^{-3} illuminated by a UV field $G_o \leq 1$ predicts a CI column density comparable with the observed one.

3.2. The on-source spectrum

The on-source CII(157μm) line flux does not differ by the average flux observed in the other positions of the map, therefore we attribute it to the diffuse DPR emission discussed in the previous section, and hence not really associated with the source itself.

The on-source spectrum also revealed pure rotational CO emission from J_{upper} equal to 14 through 18, the first two rotational backbone transitions of the water and the 163μm line of the OH, blended with the CO:16→15 line. Finally, strong OI(63μm) line emission was detected on-source. We discuss separately the origin of the observed molecular and OI(63μm) line emission in the next two paragraphs.

3.3. The molecular emission

A LVG model, applied to a slab, was used to intepret the observed CO emission. The collisional excitation rates are from McKee et al (1982) and we adopted [CO] / [H_2] = 10^{-4} (van Dishoeck et al 1995). We considered a velocity equal to 10 km s^{-1}, as measured by the CO:2→1 transition (Walker et al 1990).

Comparison of the observed CO spectrum with the model computations demostrates that the CO lines observed by LWS cannot uniquely constraint the density and temperature parameters. The emission in principle can be explained either originating in a very dense ($\sim 10^7$cm^{-3}), compact ($\sim 8 \cdot 10^{15}$cm) and warm ($\sim$ 200 K) gas *or* to arise from a dense ($\sim 10^4$cm^{-3}), more diffuse ($\sim 8 \cdot 10^{16}$cm) and hot ($\sim$ 2000 K) gas. However, the denser and colder hypothesis seems to be unlikely. In fact, at such densities gas and dust are thermally coupled and a 30 $L_\odot$ source would only heat the dust (and consequently, the gas) up to about 50 K at $r \sim 8 \cdot 10^{15}$cm. Although in principle a possibility, we disregard this solution also in the light of the following discussion (see Ceccarelli et al 1997c for a full discussion of this point).

In fact the hot and diffuse hypothesis is strongly supported by observations made in the CO:6→5 transition toward IRAS16293-2422 (Ceccarelli et al 1997b). CO:6→5 emission is extended about 14"x80" and both the broadened line profiles and the spatial distribution clearly indicate it comes from the outflowing gas. By adding the 6→5 point to the LWS observed CO lines gives a very stringent limit to the density, temperature and on the slab depth of the emitting gas, that results to be $3 \cdot 10^4$cm^{-3}, 1600 K and $5 \cdot 10^{15} cm$ respectively. The observed CO spectrum and the best fit model are shown in Figure 3, along with the 4→3, 3→2 and 2→1 emission measured by White 1996, which also support this interpretation.

Assuming that the water lines originate in the same hot gas, we obtain [H_2O]/[H_2] = $2 \cdot 10^{-5}$. We emphasize here that we cannot rule out a different origin for

1997IAUS..182P..66C

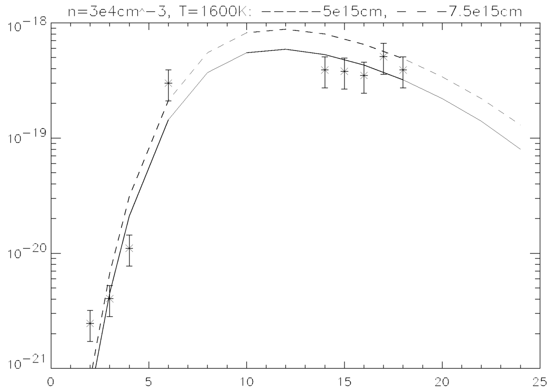

Fig. 3.— On-source CO spectrum

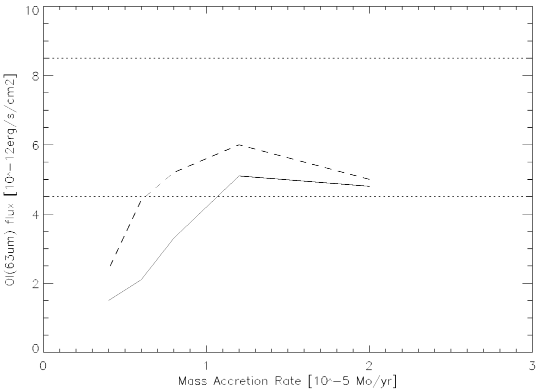

Fig. 4.— OI(63μm) line flux versus mass accretion rate.

these lines though, given the detection of only two lines. Finally, we estimate [OH]]/[H_2] = 10^{-6}.

3.4. The diffuse OI(63μm) line emission

Previous observations of OI(63μm) obtained with KAO in this region showed a correlation with the CO:2→1 emission; in particular OI(63μm) showed a strong signal ($9.5 \cdot 10^{-19}$W cm^{-2}) at the peak of the west red lobe, marked WR in Figure 1 (Ceccarelli et al 1997a). The LWS observations failed to find OI(63μm) associated with the outflow: the only clear detection were at on-source and both LWS and KAO gives the same flux at this position ($6 \cdot 10^{-19}$W cm^{-2}), despite the different beams (80" LWS and 43" KAO). While the absence of OI(63μm) emission in the two KAO positions of the blue lobe of the outflow may be attributed to the low integration of the LWS observations, the failure in detecting the KAO peak at the WR position can have only one explanation: the OI(63μm) comes from a tiny region, covered by the KAO observations, and missed by the LWSmap footprint. This gives us a clear information about the spatial distribution of the OI(63μm): we have a clear detection at r$\sim 4 \cdot 10^{16}$cm (the KAO observation beam) and then again even a stronger signal at about r$\sim 1.2 \cdot 10^{17}$cm. Between these two distances there is a gap in the OI(63μm) line emission.

3.5. The outflow

We think that this strong signal at r$\sim 1.2 \cdot 10^{17}$cm traces the violent interaction of the (proto)stellar wind with the surrounding medium. The gas, travelling at a rather high velocity ($\sim$ 100 km s^{-1}?), is shocked in the impact and heated to temperatures where all the molecules are photodissociated and the gas is mainly cooled via emission of the OI(63μm) line (the so-called J-shock: Hollenbach & McKee 1989).

On the other hand, we see diffuse emission originating from a rather hot gas, traced by the CO, that starts closer to the central source and is detected in the on-source LWS beam. Here we see the gas shocked at a much lower temperature, only around 1600 K, insufficient to dissociate the molecules but still warm enough to initiate the endothermic reactions that form the water, we see in high abundance. This situation is well described by the so-called low-velocity C-shock model(Kaufman & Neufeld 1996.

The luminosity of the molecular transitions from the hot gas is more than 10 times greater than that of OI(63μm) luminosity, and this rules out a picture in which the molecular shock is the secondary shock of a momentum conserving wind shock (see for example Hollenbach 1985). The most plausible picture is that the molecular emission traces a low velocity shock, given by the oblique impact of the wind with the cavities of a wall created by the wind itself and whose shock head is traced by the OI(63μm) line emission.

3.6. The on-source OI(63μm) line emission and the infall

It remains to explain the origin of the OI(63μm) line emission seen on-source, which, given the observed gap, is unlikely to originate in the wind shock. It is intriguing then to check what would be the emission of this line from the collapsing envelope that sourrounds IRAS16293-2422. Recently Ceccarelli et al. (1996) modeled self-consistently the infalling protostellar envelopes. We report in Figure 4 the predictions of this model for a source of 30$L_\odot$ (continuum line) as function of the mass accretion rate, a major parameter affecting the OI(63μm) line luminosity. The dashed line refers to two 15$L_\odot$ sources, where evidently two similar envelopes are assumed to surround the two objects of the binary system. Finally, the dotted lines shows the range of observed value, taking into account the 30% of absolute calibration uncertainty.

The agreement with the observed value is striking: the model well accounts for the OI(63μm) emission if the mass accretion rate is larger than about $10^{-5}M_\odot yr^{-1}$. We are conscious that this interpretation is still speculative and that high spectral resolution observations of the OI(63μm) line are mandatory in order to asses if the origin of this line close to the source is from the collapsing envelope.

A simultaneous analysis of the continuum spectrum, giving the dust ad density profile, will also provide further constraints on the parameters derived here.

4. Conclusions

We presented here observations toward the region of IRAS16293-2422 obtained with the ISO LWS. Grating spectra between $43 \mu m$ and $197 \mu m$ were acquired in a region covering the outflow observed in the CO:2→1 transition. The observations reveal the presence of a weak CII($157 \mu m$)emission, resulting from illumination by a faint UV field ($G_o \leq 1$). A deep grating integration on-source detected several lines from CO, H_2O and OH molecules, together with emission from the OI($63 \mu m$) line. These molecular lines originate in a hot (~ 1600 K) and dense ($\sim 3 \cdot 10^4$ cm^{-3}) gas, intepreted in terms of a C-type shock caused by the oblique impact of the wind with the walls of the cavity formed by the wind. The head of the shock, when the wind strikes the static ambient gas, is traced by a strong OI($63 \mu m$) line emission peak seen by the KAO at $\sim 1.2 \cdot 10^{17}$cm from the central source. Finally we speculate on the origin of the OI($63 \mu m$) line emission seen on-source, as due to the thermal emission of the collapsing envelope. [1]

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