ISO LWS OBSERVATIONS OF H_2O FROM R CAS:

A Consistent Model For Its Circumstellar Envelope

TRUONG-BACH AND NGUYEN-Q-RIEU
Observatoire de Paris, DEMIRM,
61 avenue de l'Observatoire, F-75014 Paris, France

R.J. SYLVESTER, M.J. BARLOW AND X.W. LIU
Department of Physics & Astronomy,
University College London,
Gower Street, London WC1E 6BT, UK

T. LIM
The LWS Instrument-Dedicated Team,
ISO Science Operations Center,
P.O. Box 50727, E-28080 Madrid, Spain

A. OMONT
Institut d'Astrophysique,
98bis boulevard Arago, F-75014 Paris, France

P. COX
Institut d'Astrophysique Spatiale, Bât 120,
Universite Paris XI, F-91405, Orsay, France

AND

C.J SKINNER
Space Telescope Science Institute,
3700 San Martin Drive, Baltimore, MD 21218, USA

Abstract. We present an ISO LWS 43-197 μm grating spectrum of the oxygen-rich AGB star R Cas. The spectrum is rich of isolated and blended H_2O lines. For their identification and in order to determine the physical parameters of the circumstellar envelope, we have constructed a model which treats radiative transfer, chemical exchange and photodissociation reactions, and various heating and cooling processes in a consistent manner. By fitting the observed line fluxes and using stellar parameters based upon the Hipparcos distance, we derived a mass-loss rate of $\dot{M} = 1\ 10^{-6}\ M_{\odot}\ yr^{-1}$ which is close to the value $6\ 10^{-7}\ M_{\odot}\ yr^{-1}$ previously derived for W Hya, another oxygen-rich AGB star.

TABLE 1. The H_2O emission lines u–l (in JK_-K_+ notations) from R Cas: $F_{\rm cal}$ and $F_{\rm obs}$, calculated and observed line fluxes, respectively; $R = F_{\rm cal}/F_{\rm obs}$ ($F_{\rm cal}$ for a blend is the sum of individual components)

u	l	λ_{vac} (μm)	λ_{obs} (μm)	Det.	$F_{\rm cal}$ (10^{-15} W m^{-2})	$F_{\rm obs}$	R	Comments
212	101	179.53	179.56	LW4	0.814	0.60	1.35	
303	212	174.63	174.64	LW4	0.252	0.39	0.65	
523	432	156.27	156.27	LW4	0.014	0.18	1.02	blend 1
322	313	156.19			0.170			blend 1
413	322	144.52	144.60	LW3	0.078	0.18	0.43	noise
313	202	138.53	138.59	LW3	0.560	0.47	1.19	
423	414	132.41	132.65	LW3	0.185	0.12	1.54	noise
404	313	125.35	125.36	LW3	0.460	0.40	1.15	
432	423	121.72	121.76	LW2	0.215	0.20	1.08	
414	303	113.54	113.72	LW2	0.729	0.67	1.09	
221	110	108.07	108.20	LW2	1.110	1.19	0.93	
634	625	104.09	103.96	LW1	0.183	0.58	0.78	blend 2
615	606	103.94			0.130			blend 2
642	633	103.92			0.140			blend 2
220	111	100.98	101.01	LW1	1.700	1.96	0.99	blend 3
514	423	100.91			0.250			blend 3
826	817	99.98	99.65	LW1	0.084	0.84	0.93	blend 4
505	414	99.49			0.700			blend 4
744	735	90.05	90.08	LW1	0.170	1.11	1.50	blend 5
322	211	89.99			1.50			blend 5
707	616	71.95	71.76	SW3	1.030	2.56	0.89	blend 6
717	606	71.54			1.100			blend 6
818	707	63.32	63.32	SW3	1.130	1.39	0.81	

1. Introduction

Because water vapour is abundant in the terrestrial atmosphere, stellar H_2O spectra are often blended with telluric H_2O emission/absorption, even with high-altitude airborne observations. Use of the Infrared Space Observatory (ISO) telescope can avoid this inconvenience inherent to ground-based observations. Infrared (IR) radiation is emitted mainly from the innermost layers of the circumstellar environnments. It is in this hot, high-density and strong radiation field region that atomic and molecular excitation processes are mostly important. Thus, ISO observations using the long wavelength spectrometers (LWS) would help us to understand the struc-

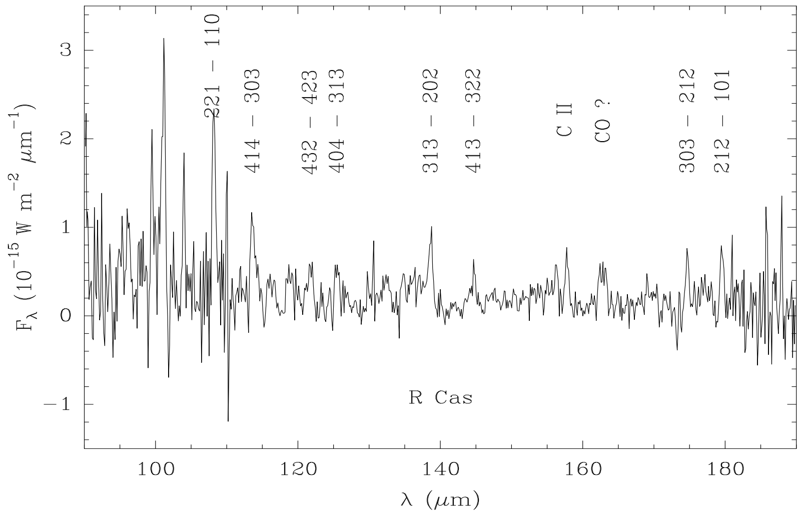

Figure 1. A portion of ISO LWS grating (continuum substracted) spectrum of R Cas. Some strong H_2O lines are labelled by their transitions

ture of the molecular envelope: its mass loss, its atomic and/or molecular abundances at highly-excited states.

We present here an LWS spectrum from 43-197 μm emitted by R Cas, an oxygen-rich Mira variable star. Our circumstellar model used to fit the observed H_2O line fluxes enabled us to derive the physical parameters of the stellar envelope.

2. Observations

The data presented here were obtained on 1996 August 5, during Revolution 263 of the ISO mission, using the LWS01 AOT. Six fast grating scans were obtained with 0.5 sec integration ramps at each commanded grating position. The spectra were sampled at 1/4 of a spectral resolution element, the latter being 0.3μm in second order (SW1-SW5; $\lambda \leq 93\mu$m). and 0.6μm in first order (LW1- LW5; $\lambda \geq 80\mu$m). The total on target-time was 1329 sec. Uranus was used for the flux calibration. The sub-spectra from the ten LWS detectors were rescaled to give the same flux in regions of overlap, adopting the flux levels from detectors SW2 and SW3 as the true values. The other detectors required changing by typically less than 20 percent. The subspectra were then merged to form a complete spectrum from 43-197 μm. A portion of this spectrum labelled with some H_2O transitions is illustrated in Fig.1. The measured H_2O line fluxes are presented in Table 1 with an estimated uncertainty better than 40%.

3. A model for H_2O emission

For R Cas, the Hipparcos parallax (Van Leeuven *et al.*, 1997) corresponds to a distance of 107 ± 12 pc and $M_{\rm bol}$ = -3.74. The angular diameter E-model of Haniff *et al.* (1995) gives stellar radius $r_* = 2\ 10^{13}$ cm and stellar effective temperature $T_{\rm eff}$ = 2415 K. The outflow terminal velocity is V_t = 12 km s^{-1} (Bujarrabal *et al.* 1989, Loup *et al.* 1993). We used the collisional rates of ortho-H_2O (o-H_2O) and para-H_2O (p-H_2O) excited by He impact (Green *et al.*, 1993), but corrected them by a factor 1.38 for the H_2 encounters. We assumed a hydrogen atome/molecule density ratio of f = 1. The gas velocity $v_e(r)$ was obtained by solving the equation of motion for the ejected gas (Goldreich & Scoville 1976). The H_2O level populations, line opacities, and heating and cooling rates for each shell were calculated by solving the statistical equilibrium, radiative transfer, chemical exchange and photodissociation reactions (of H_2O and OH) coupled equations (Goldreich & Scoville 1976, Truong-Bach *et al.* 1990, 1991).

We have obtained practically the same radial kinetic temperature and particle densities as functions of radius from the o-H_2O and the p-H_2O fits. The photodissociation effect was found to be negligible. Table 1 gives the comparison between the predicted and observed integrated H_2O line fluxes. The modelled/observed values agree very well. Here for each blending labelled "n", the observed flux is compared to the sum of the predicted line flux components. The derived mass-loss rate, 1 10^{-6} $M_\odot$ yr^{-1}, is close to the value of 6 10^{-7} $M_\odot$ yr^{-1} found for W Hya, another O-rich AGB star of similar stellar characteristics (Barlow *et al.*, 1996).

While this paper was being written, we have obtained another LWS spectrum which shows better s/n and H_2O lines stronger than those observed ~270 days earlier. Detailed results and discussion are out of the scope of this limited paper and will be given elsewhere (Truong-Bach *et al.* 1998) *.

* *Note added in proof* - We have obtained meanwhile SWS results.

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