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Research Note

Limits on molecular emission from the planetary nebula associated with Sakurai's object

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Abstract. We have observed Sakurai's object in the S(1)$\lambda 2.121$ line of H_2 and in the $J = 2 \rightarrow 1$ line of ^{12}CO. We give upper limits on the H_2 and ^{12}CO emission from the planetary nebula associated with this object. Assuming a distance of 3.8 kpc, we obtain an upper limit on the mass of molecular hydrogen in the planetary nebula of $1.8\,10^{-4}\,M_\odot$ for an excitation temperature of 1000 K and, for an excitation temperature of 25 K, an upper limit of $1.5\,10^{-5}\,M_\odot$ on the mass of CO.

Key words: stars: circumstellar matter – infrared: ISM: lines and bands – radio lines: ISM – Sakurai's object = V 4334 Sgr

1. Introduction

'Sakurai's object' (V4334 Sgr) was originally reported as a possible 'slow nova' (Nakano 1996). However optical spectra obtained shortly after discovery by Cappellaro (1996) revealed a high luminosity star of spectral type early G displaying numerous absorption lines. Furthermore it seems that it began to brighten as early as 1995 January. The slow rise to maximum, over a period of 14 months, coupled with the absence of any emission lines, is clearly inconsistent with a nova in eruption. Shortly after discovery, Duerbeck & Pollaco (1996) reported a planetary nebula (PN) centred on Sakurai's object; the spectrum of the PN is typical of old, low–moderate excitation PNe (Duerbeck & Pollaco 1996). The visual light curve, the low excitation spectrum and the PN led Duerbeck & Pollaco (1996) to suggest that this object may be undergoing a final helium flash.

Radio observations of Sakurai's object are reported by Eyres et al. (1998a), who find radio emission from the PN. They estimate a distance of 3.8 kpc, considerably lower than the 8 kpc deduced by Duerbeck & Benetti (1997; see Eyres et al. 1998a for detailed discussion). Infrared observations are described by Eyres et al. (1998b), who report the presence of absorption in the ^{12}CO and ^{13}CO first overtone band at 2 μm, possibly arising in an extended envelope or a circumstellar shell.

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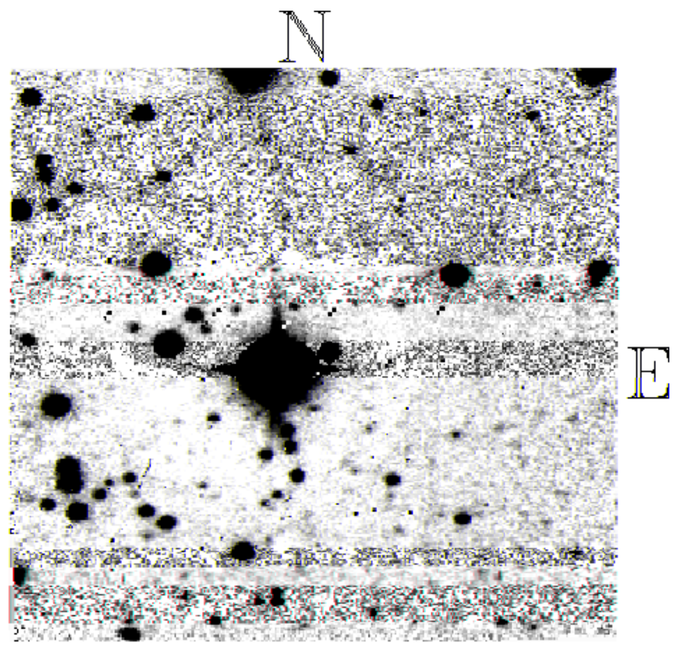

Fig. 1. S(1) image of Sakurai's object, which is the bright object located at the centre of the field; the J2000 position is $\alpha = 17^{h}52^{m}32\overset{s}{.}7$, $\delta = -17^\circ 41' 08\overset{''}{.}0$. The field-of-view is 1.22′ square. The effective exposure time is 12 minutes in the center of the image, but less at the edge, due to the movement of the telescope between the individual exposures.

H_2 (Webster et al. 1988) and CO (see e.g. Huggins et al. 1996) emission are commonly seen in a neutral molecular envelope surrounding the ionized gas in PNe and we describe here observations of Sakurai's object in the H_2 S(1) $\lambda 2.121$ line with the United Kingdom Infrared Telescope (UKIRT), and in the $J = 2 \rightarrow 1$ ^{12}CO transition with the James Clerk Maxwell Telescope (JCMT).

2. Observational details

2.1. Infrared

We obtained images in the S(1) $\lambda 2.121$ line of H_2 and adjacent continuum ($\lambda = 2.136\,\mu$m) with the IRCAM3 array on UKIRT

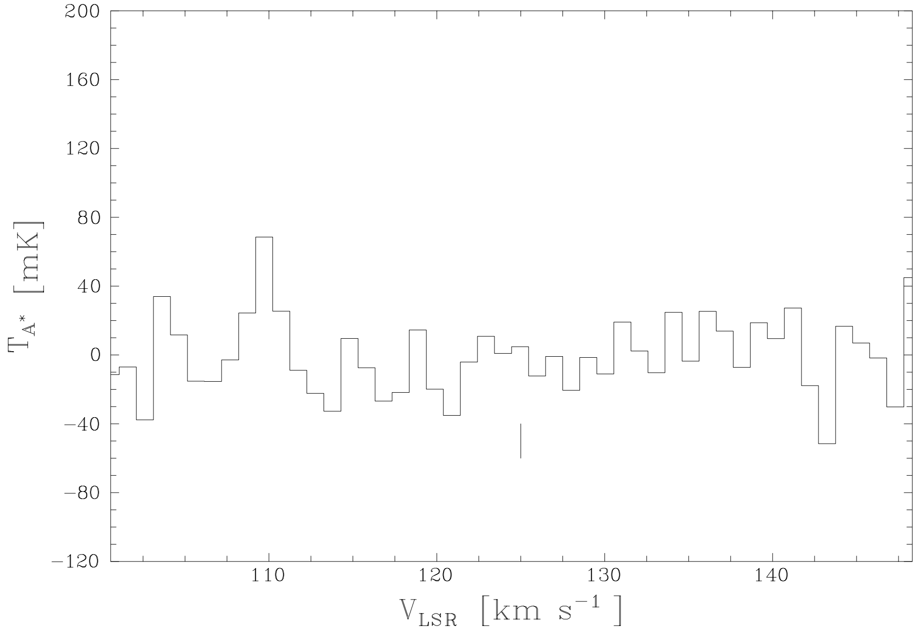

Fig. 2. The spectrum of Sakurai's object in the region of the $J = 2 \rightarrow 1$ transition of ^{12}CO; the vertical tick mark is at the $V_{\rm LSR}$ of the object, $+125\,{\rm km\,s^{-1}}$ (Duerbeck et al. 1997).

on 1997 July 17. Our observation consisted of groups of 8 frames of 30 seconds each (made up of either 6 or 30 co-adds), the telescope being moved a small fraction of the field-of-view between each image. We obtained 3 such cycles in the S(1) line and in the 2.1 μm continuum, making a total of 12 minutes integration in each band. The images were first dark subtracted, and then flat-fielded using a median stack of the other images within the group.

The summed S(1) image is shown in Fig. 1.

2.2. Millimetre

Sakurai's object was observed during service time on 1997 June 29 with the heterodyne receiver A2 on the JCMT tuned to the ^{12}CO $J = 2 \rightarrow 1$ line. The observations consisted of three sets of 600-sec observations with the stellar component at the centre of the beam; each set of observations consisted of 10 individual 60 second integrations. We beamswitched in azimuth at a frequency of 1 Hz to a reference position $120''$ away from the star and integrated for a total of 600 sec at the reference position. The system temperature was 400 K. The JCMT beamwidth at the frequency of the CO $J = 2 \rightarrow 1$ line is $22''$, compared with the $32''$ diameter of the PN associated with Sakurai's object (Duerbeck & Benetti 1997).

The individual JCMT spectra were coadded and binned, a linear baseline removed, and the resultant spectrum in the $V_{\rm LSR}$ range 100 – $150\,{\rm km\,s^{-1}}$, which should include any emission at the $V_{\rm LSR}$ of Sakurai's object ($125\,{\rm km\,s^{-1}}$; Duerbeck et al. 1997), is shown in Fig. 2.

3. Results and discussion

3.1. H_2 emission

The H_2 image (Fig. 1) shows no obvious nebulosity on the scale of the optical nebulosity (cf. Webster et al. 1988). However there is some structure in the sky, which we attribute to flatfielding errors. We use this, together with an observation of a standard star, to obtain an upper limit of $7\,10^{-19}\,{\rm W\,m^{-2}}$ arcsec^{-2} on the H_2 emission. This is for small scale structure, any structure whose size is comparable with the field-of-view ($1.2' \times 1.2'$) will be washed out by our flatfielding technique. Assuming an excitation temperature of 1000 K for H_2 (see e.g. Cox et al. 1997) and distance 3.8 kpc, the above limit on the H_2 intensity translates to an upper limit of $1.8\,10^{-4}\,{\rm M_\odot}$ on the mass of molecular hydrogen in the area defined by the optical PN.

3.2. CO emission

We deduce a 3σ upper limit of $T^*_{\rm A} < 70\,{\rm mK}$ for the peak emission at a resolution of $1\,{\rm km\,s^{-1}}$, and a 3σ upper limit of 0.6 K–km s^{-1} on the line flux over $V_{\rm LSR}$ range 100. . . 150 km s^{-1}. The mass (in ${\rm M_\odot}$) of CO in the JCMT beam is given by $2.8\,10^{-8} D^2 F f$, where D is the distance in kpc, F is the flux in K–km s^{-1} and f is a function of the CO excitation temperature. The excitation temperature of CO in PNe in which the CO is optically thin is typically 25 K (Bachiller et al. 1993). We assume this value here and therefore have a 3σ upper limit on the mass of CO of $1.5\,10^{-5}\,{\rm M_\odot}$ for distance $D = 3.8$ kpc.

We also note that, where CO has been observed in PNe at millimetre wavelengths, it tends to be 'clumpy' and to occupy a neutral envelope which lies outside the ionized region (e.g. Forveille & Huggins 1991; Jaminet et al. 1991). In view of the fact that the PN associated with Sakurai's object is comparable in size with the beam of the JCMT at 230 GHz, it is possible that our observation may have missed any CO present in an extended molecular envelope. Further observations would be useful to check this.

4. Conclusions

We have observed Sakurai's object at IR and at millimetre wavelengths, and found an upper limit on the emission in the H_2 S(1) $\lambda = 2.121\,\mu$m line, which corresponds to an upper limit on the mass of H_2 of $1.8\,10^{-4}\,M_\odot$ for a distance of 3.8 kpc and excitation temperature 1000 K. We also find an upper limit on emission in the $J = 2 \rightarrow 1$ transition of ^{12}CO; the corresponding upper limit on the mass is $1.5\,10^{-5}\,M_\odot$ for excitation temperature 25 K. The mass of molecular material commonly associated with PNe is typically in the range $\lesssim 10^{-4} \ldots 1\,M_\odot$ (Huggins & Healy 1989; Huggins et al. 1996), with PNe exhibiting strong CO emission generally being associated with high mass progenitors. The limits we have obtained therefore seem consisent with a low mass progenitor for Sakurai's object. We also note that our limits on molecular mass are significantly less than the mass of ionized gas in the PN associated with Sakurai's object, for which Eyres et al. (1998a) give a lower limit of $2.5\,10^{-2}\,M_\odot$.

Continued monitoring of the molecular content of the PN associated with Sakurai's object would be valuable as it continues to evolve.

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