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Balloon Observations of the 557 GHz Line of Water Vapour

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Abstract. We report the first results of PIROG 7, a balloon-borne platform equipped with a 60 cm telescope and a heterodyne receiver designed for observations of the ground transition at 557 GHz of ortho-water. Gas-phase water is expected to be one of the primary coolants of dense molecular regions, but its presence in the atmosphere has prevented observations of non-masering low-excitation lines up to now. An absorption line was detected at a $V_{lsr} \sim 10$ km/s towards Orion, and constitutes the first measurement of this line from the ISM. This line can be interpreted as a self-reversal of a very broad and bright emission line, arising in the hot core of the KL/BN region. The characteristics of the absorption are consistent with available information on this region, including the recent detection at 548 GHz of the isotopic species of water. One interesting consequence of the absortion line is the lack of a bright 'spike' component from the 'ridge',which implies a quite low fractional water vapour abundance,$< 10^{-8}$ for this main cloud component.

1. The PIROG7 experiment

The PIROG (Pointed IR Observation Gondola) Platform was originally developed for wide-field far infrared observations (the CII line at 158 μm), but in our latest experiment we used a new set-up based on a heterodyne receiver. The gas-jet stabilized gondola carried a 60 cm telescope and two CCD cameras were used for aquisition and guiding. The experiment was launched on May 2, 1994, from the CNES balloon launching range in Air sur l'Adour in southern France. The launch was smooth, and the float altitude (39 km) was reached after 2.5 hours. After a stabilisation period of about one hour (both for the gondola attitude control system and the front end of the receiver) observations of the water line emission from the atmosphere and from the Orion BN/KL region could be performed. Once stabilised, all systems worked as planned except an optical quadrant detector mounted in the front end of the receiver and intended to verify the alignment of the fixed mounted CCD camera and the telescope. This detector was saturated by scattered light, but we still feel confident that

the pointing was correct, since the two CCD cameras (mounted on each side of the main telescope) kept their alignment as defined before launch.

2. Results

In order to determine the atmospheric attenuation we observed the sky emission at different telescope elevations. These measurements are described in detail by Tauber et al. (1995) and they basically confirm the model calculations by D. Murtagh (private communications). The radial velocity of Orion in the beginning of May is high enough to make observations possible - but it should be noted that any blue wing emission will suffer from large attenuation.

The astronomical observations suffered from a standing-wave problem; the amplitude was high and the phase was slowly drifting. On the other hand, two Fourier components were enough to accurately simulate the baseline and for any narrow feature the baseline definition should not be any problem. The residual spectrum, after removal of the standing wave, is shown in Fig. 1. Instead of a prominent emission line, a faint and narrow absorption line is seen at the radial velocity of Orion BN/KL. We have carefully tested sub-sets of our data to investigate if this feature may originate in some noise spike, but it does in fact seem to be real. It must be emphasised, however, that this absorption could well be a self-reversal of a broad and strong emission line masked by the standing wave.

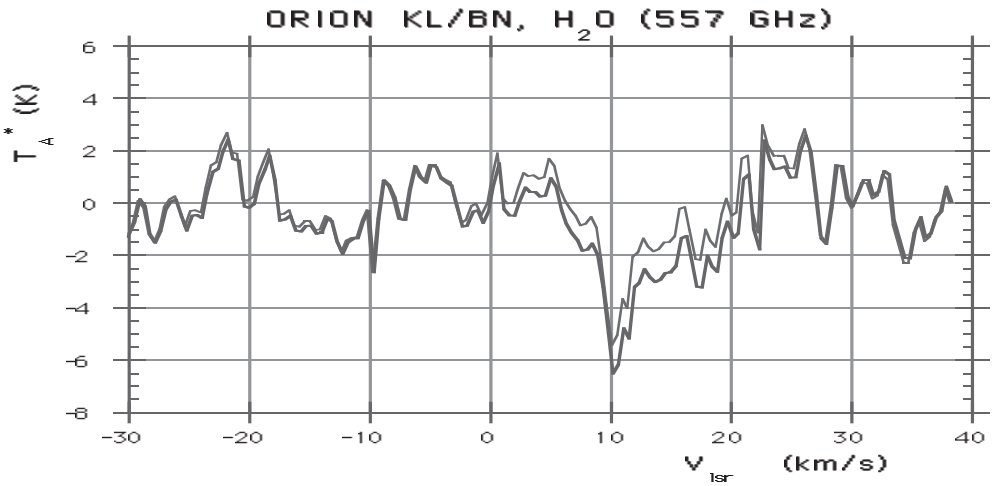

Fig. 2. Our observations of Orion KL/BN reveal a marginally detected absorption feature at a radial velocity which agrees with the isotopic water vapour emission at 548 GHz observed by Zmuizinas et al. (1994). Due to an excessive standing wave, the baseline subtraction was uncertain. The thick curve corresponds to a narrow "gap" (20 channels = 8.6 km/s) in the baseline fit and the thin curve corresponds to a "gap" twice as broad - the absorption seems to become deeper and wider with increasing "gap". Extended wing emission may well be present but remained undetected due to our baseline problems.

3. Discussion

Recent KAO observations of the $H_2{}^{18}O$ ground transition line at 548 GHz by Zmuidzinas et al. (1994) reveal a broad line with a peak intensity of 0.55 K and if we

simply scale by the isotopic ratio $^{16}O/^{18}O = 500$ relevant for Orion (Scoville et al., 1983) the expected 557 GHz line in the PIROG beam would have a peak intensity of more than 100 K. *Such a bright line can be completely ruled out by our observations.* Consequently optical depth effects must be present. This is hardly surprising, but the question is if we can explain an absorption (or self reversal) line, in contrast to the emission lines normally observed from this region.

We first note that the dust continuum is too faint as a background for a 5 K absorption line; interpolation of available observations (e.g. Keene et al., 1982 and Jaffe et al., 1984) indicate about 3 kJy in the beam of PIROG (3.7') which is an order of magnitude too faint. Thus, the only way to get an absorption line of the observed strength is to assume a broad line emission as a quasi-continuum. As the isotopic line at 548 GHz has a total width of about 50 km/s (Zmuidzinas et al., 1994) this seems reasonable. What remains to be explained is the reason for the 557 GHz to be self-reversed while other - also very optically thick - lines, such as the CO lines, are not.

In a way it seems more difficult to understand why the CO lines do not show self-reversals as there should be plenty of cold fore-ground gas. The broad line component (often referred to as the 'plateau' feature) probably originates from a (more or less) bipolar outflow centred at IRc2 and directed in the line of sight (see Schulz et al., 1995). Instead of a narrow absorption feature an emission spike is observed. This 'spike' has a larger (elongated) spatial distribution and is referred to as the 'ridge' component. This means that the coupling telescope beam/source component is different for the two components (e.g. Schulz et al., 1995, estimate $\eta = 0.06$ for the plateau component and $\eta = 0.14$ for the ridge component) and a possible narrow absorption feature may well be masked by ridge emission.

If this is a correct interpretation, then we can use the lack of ridge emission in the 557 H_2O line to put a limit on the water abundance in the ridge. Assuming a kinetic temperature of 70K, a number density of $10^5 cm^{-3}$ and a column density of $3\ 10^{23} cm^{-2}$ (Genzel & Stutzki, 1989) and using an LVG code developed by P. Bergman (private communication) we find an upper limit of 10^{-8} for the fractional abundance of water vapour in the ridge. On the other hand,the absorption component indicates an optical depth of about unity (or more) and this means that a column density of $10^{13} cm^{-2}$ is required and if we adopt 10^{-8} as an upper limit of the fractional abundance of water vapour this means a hydrogen column density of at least $10^{21} cm^{-2}$ - a quite modest request in this context, and we don't run into a contradiction.

One may wonder if anything can be said about the location of the 'reversing layer'. The fact that we are discussing a resonance line means that absorbed photons are generally re-emitted at a nearby frequency provided the density does not approach the 'critical' density ($5\ 10^8 cm^{-3}$) and it is more adequate to talk about (resonance) scattering. As a consequence, scattered photons from a large region around the hot central source may enter the beam and compensate for the loss in the direct view. The structure of the surrounding cloud(s) is thus important for the observed line profile. A small foreground cloud (with $N(H_2) > 10^{21}$) would be efficient in scattering away

the central part of the broad emission line, but there are other possibilities. One is the case where the border of the outflow region has a relatively high water vapour abundance and a very large optical depth - a case which in fact is in accordance with the results of Cernicharo et al. (1994) who observed extended emission from the 183 central reversal would result in the line profile. Our LVG calculations show that an optical depth of $10^3 - 10^4$ is required for thermalization of the lowest levels and for a water abundance of 10^{-5} this means that this layer should have a column density of (at least) $N(H_2) = 10^{21} - 10^{22} cm^{-2}$, which is not unreasonable. In this context it should be mentioned that Knacke and Larson (1991), who observed four water lines in the near IR spectrum of the BN object, estimated a column density $N(H_2O)$ = 2 $10^{17} cm^{-2}$. For a fractional abundance of 10^{-5} this corresponds to $N(H_2)$ = 2 $10^{22} cm^{-2}$.

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