Water Vapour in Markarian 231

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Summary

Ultra Luminous InfraRed Galaxy (ULIRG) Mrk231 reveals up to seven rotational lines of water (H_2O) in emission, including a very high- lying (Eupper = 640 K) line detected at a 4σ level, within the Herschel/SPIRE wavelength range (190 < λ(μm) < 640), whereas PACS observations show one H_2O line at 78 μm in absorption, as found for other H_2O lines previously detected by ISO. The absorption/emission dichotomy is caused by the pumping of the rotational levels by far-infrared radiation emitted by dust, and subsequent relaxation through lines at longer wavelengths, which allows us to estimate both the column density of H_2O, and the general characteristics of the underlying far-infrared continuum source. The highest-lying H_2O lines detected in emission, with levels at 300 − 640 K above the ground state, indicate that the source of far-infrared radiation responsible for the pumping is compact (radius= 110 − 180 pc) and warm (T_{dust} = 85 − 95 K), accounting for at least 45% of the bolometric luminosity. The high column density $N(H_2O)$ ~ 5×10^{17} cm^{-2} found in this nuclear component, is most probably the consequence of shocks/cosmic rays, an XDR chemistry, and/or an "undepleted chemistry" where grain mantles are evaporated. A more extended region, presumably the inner region of the 1-kpc disk observed in other molecular species, could contribute to the flux observed in low-lying H_2O lines through dense hot cores, and/or shocks. The H_2O 78 μm line observed with PACS shows hints of a blue-shifted wing seen in absorption, maybe indicating the presence of H_2O in the prominent outflow detected in OH (Fischer et al., this symposium).

Background: One key question in the study of composite infrared (IR) merging galaxies and quasi-stellar objects (QSOs) is what fraction of their luminosity is generated in the nuclear region (<200 pc) associated with the Active Galactic Nucleus (AGN) and a possible extreme nuclear starburst, and what fraction arises from a more extended kpc-scale starburst. The observation of molecular species such as OH and H_2O at far-IR wavelengths is ideal for studying such a issue, because their high-lying rotational levels are pumped through absorption of far-IR radiation and the observable excitation is then sensitive to the far-IR radiation density that in turn depends on the compactness of the far-IR continuum source. In addition, these molecular observations shed light on the dominant chemistry in those nuclear regions.

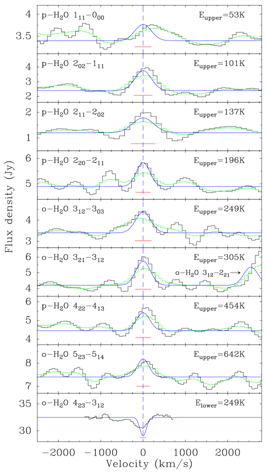

Figure 1: Comparison between the observed spectra (black and green histograms: unapodized and apodized spectra) and model results (dark blue lines; a Gaussian instrumental line shape with FWHM=0.048 cm^{-1} is used for simplicity. The 3_{12}-2_{21} line is blended with CO (10-9). The red segment in each panel indicates the FWHM of an unresolved line. The velocity scale has been calculated with respect to the systemic redshift of z=0.04217.

Observations: We detect 7 H_2O lines in emission with SPIRE (HerCULES Programme), and 1 line in absorption with PACS (SHINING Programme). The lines peak at central velocities, but the PACS line shows a relatively weak blue-shifted wing extending up to -800 km/s, suggesting that H_2O also participates in the prominent outflow detected in OH (Fischer et al.,this symposium). The ground-state H_2O lines are not detected.

Models: The observed pattern of line emission/absorption cannot be explained in terms of pure collisional excitation. The excitation mechanism for the high-lying lines is the pumping by far-IR photons emitted by dust in a compact/warm far-IR continuum source that dominates at 20μm<λ<70μm. We find a high $N(H_2O)\approx5\times10^{17}$ cm^{-2}, and an abundance of $\chi(H_2O)\approx10^{-6}$. The combined analysis of absorption/emission lines is a powerful tool to establish the distribution of H_2O relative to the warm dust responsible for the excitation; a "mixed" approach is favoured.

Conclusions: Radius of the warm component: 110-180 pc, luminosity of $\approx1.9\times10^{12}$ Lsun, dust temperature of 85-95 K, $N(H_2O)$ $\approx5\times10^{17}$ cm^{-2}. Main scenarios: shocks, XDR, "undepleted" chemistry. A multi-species analysis is required to identify the dominant process.

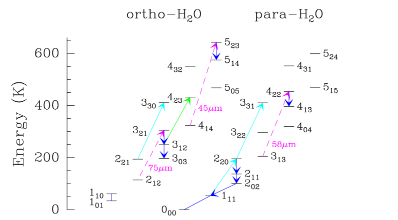

Figure 2: Energy level diagram for H_2O, showing the detected/undetected (blue arrows/lines) lines with SPIRE, the line detected with PACS (green) and those detected by ISO (light blue). Dashed red arrows indicate the main pumping paths for the high-lying lines observed with SPIRE. Upward (downward) arrows: absorption (emission) lines.

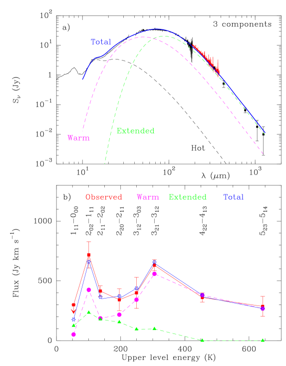

Figure 3: Comparison between observations and model results. a) Continuum emission from Mrk 231. Spitzer IRS data, ISO data, and SPIRE data (red spectrum) are shown. Our 3 components fitting model is shown with dashed lines, and the total modeled emission with a solid blue line. b) H_2O emission. The high-lying lines are generated in the warm/compact region (violet), whereas the extended kpc-scale starburst (green) is expected to contribute to the low-lying lines.