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Intensity ratios for XDR/PDR identification

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Abstract. The intensity ratios of HCO^+/HCN and HNC/HCN (1−0) reveal the relative influence of star formation and active galactic nuclei (AGN) or black holes on the circum-nuclear gas of a galaxy, allowing the identification of X-ray dominated regions (XDRs) and Photon-dominated regions (PDRs). It is not always clear in the literature how this intensity ratio calculation has been, or should be performed. This paper discusses ratio calculation methods for interferometric data.

Keywords. astrochemistry, galaxies: active, galaxies: ISM, ISM: molecules, stars: formation

1. Introduction

An understanding of the interplay between star-formation and AGN is crucial in comprehending how galaxies form and evolve. HCN, HCO^+ and HNC (1−0) ratios can be used to identify XDRs and PDRs (Meijerink et al. 2007). These are regions of gas whose chemistry is dominated by X-rays from a black hole or AGN and FUV radiation from star formation respectively. Their presence indicates whether the black hole or the star-formation has the greater impact on local regions of the circum-nuclear molecular gas.

According to the high density regime models ($>10^4-10^{6.5}$ cm^{-3}) of (Meijerink et al. 2007) HCO^+/HCN and HNC/HCN (1−0) intensity ratios >1 indicate the presence of an XDR, while ratios $\leqslant$1 indicate the presence of a PDR. But how should intensity ratios be calculated from interferometric data?

2. Choice of region and spectra type

Intensity ratios can be calculated from spectra taken over a spatial region. The same spatial region must be used for each molecular line so that the same number of pixels contribute to each point on the spectra. This ensures the data for all 3 molecular lines are directly comparable and therefore suitable for the calculation of the ratio.

The largest emission region (encompassing all pixels in all lines with values $>3\sigma$) should be used as it contains all significant emission from all lines. It must also be considered that the 3σ emission region of the weakest line (probably the HNC), likely covers a smaller area. For this reason an integrated (sum over area), rather than an average spectra (mean over area), should be produced so pixels with little to no emission do not affect the spectra or the ratio.

3. Ratio calculation methods

Intensity ratios can be calculated by division of the: peak intensity (peak height), the velocity integrated peak intensity (peak area) or of the integrated intensity (moment zero) maps. Individual Gaussian components aligning in velocity should be divided separately to produce individual ratios as they likely originate from spatially distinct regions.

Division of the velocity integrated intensities of the spectra provides a numerical ratio value but no spatial information on ratio region size or ratio variation. This method allows a simple error estimate to be made and takes into account linewidth, therefore providing a better estimate of the ratio value if the lines are of similar peak intensity. This is currently the standard method of intensity ratio calculation for XDR/PDR identification (e.g. Baan *et al.* 2008). Intensity ratio maps can also be produced by division of spatial, integrated intensity maps. This method provides an indication of the spatial variation of the ratio and size of the chemical region. However, errors would have to be communicated in the form of a difficult to read error map, in contrast to the simple numerical error estimate of the other calculation methods.

The ratios calculated only apply to the spatial scales sampled within the local regions observed and do not represent the global chemical conditions of the galaxy. Furthermore it must be noted that as little as a 10% contribution from a PDR in the local region observed can suppress emission lines that would otherwise be enhanced by an XDR (Meijerink *et al.* 2007). Consequently, it may only be possible to detect XDRs at very high resolution if there is a PDR contribution from a starburst ring (Martín *et al.* 2015).

4. Conclusions

Line intensity ratio maps display the spatial distribution and variation of the molecular ratios but do not give a simple error estimate. On the other hand, the numerical velocity integrated ratio provides a simple error estimate, but no indication of the size of chemical regions present or any indication of spatial variations of the ratio. We therefore encourage that both numerical intensity ratios and spatial ratio maps be employed together to robustly identify XDRs and PDRs in the circum-nuclear region of galaxies.

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