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What Sort of Standard Candle is Orion for Studying Molecular Hydrogen Line Emission in Galaxies?

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Abstract

The total shocked and fluorescent molecular hydrogen 1–0 S(1) line luminosities from Orion have been measured to be ~ 2.5 $L_\odot$ and ~ 2.0 $L_\odot$, respectively. The implications for using Orion to study the interstellar medium in galaxies is discussed.

Introduction : Orion as a Standard Candle

The star-forming complexes in galaxies are often likened to a conglomeration of Orion-like regions (perhaps 10^5 in a classical starburst). This comparison is invoked across much of the electromagnetic spectrum and, of relevance here, to H_2 near-IR line emission. There are, of course, several important questions which should first be asked : is Orion typical of H_2 line emitting sources in our galaxy, or is it in some special type of evolutionary phase? Do Orion-type regions dominate the H_2 line emission from galaxies, or do particularly exotic star-forming complexes such as DR 21 (Garden *et al.* 1986, 1989) or supernova remnants such as IC 443 (Burton *et al.* 1988, Burton 1988) or RCW 103 (Moorwood *et al.* 1988) dominate the global emission? Even if we assume that Orion-type regions are typical, how well do we understand its H_2 line emission? It is the purpose of this paper to discuss this last point. Estimates will be presented of the global H_2 line emission from Orion, with the contributions from shocks and fluorescence. The intention is to provide a calibration for the Orion standard candle, so that it may be better used to make comparisons with the line emission from galaxies.

H_2 line emission was first detected from Orion by Gautier *et al.* (1976), and mapped by Beckwith *et al.* (1978); the total luminosity in the 1–0 S(1) line, at 2.12 μm, was measured to be 2.5 $L_\odot$, not correcting for extinction. On the basis of vibrational line ratios, and also the evidence for high-velocity motions and broad line widths in the source (*e.g.*, Nadeau & Geballe 1979), it was concluded that the emission was shock-excited. There is a molecular hydrogen reflection nebula around the shocked region (Hough *et al.* 1986), resulting from the scattering of line radiation arising near the peak of the shocked region, and extending at least 80" from the peak. UV-radiation from the Trapezium star cluster has created a photodissociation region (*e.g.*, Tielens & Hollenbach 1985) lying on the front surface of the shocked region, and excites H_2 molecules by fluorescence (*e.g.*, Hayashi *et al.* 1985, Burton *et al.* 1989). Some of the fluorescent line emission may have the appearance of shocks since the gas density is high ($\succeq 10^5\,cm^{-3}$) in much of the region, and collisional redistribution of radiatively-excited levels of the H_2 molecule can produce a thermal distribution for low-lying vibrational levels (*e.g.*, Burton, Hollenbach & Tielens 1989).

The H_2 line emission from external galaxies has been compared with that from Orion (*e.g.*, Fischer *et al.* 1983, Joseph *et al.* 1984, Kawara *et al.* 1987, Fischer *et al.* 1987). On the assumption that the Orion emission is shocked, and in the absence of measurements of additional transitions, the similarity of the observed L_{H_2} / L_{IR} ratios is often invoked to associate the extragalactic 1–0 S(1) emission with shocks powered by vigorous star formation activity. The recent multi–transition study by Puxley *et al.* (1988, 1989), and their consequent suggestion that much of the extragalactic H_2 emission is fluorescent, casts doubt on this picture, though the low spectral resolution of their data complicates the extraction of accurate line fluxes.

Observations and Analysis

The data upon which this analysis is based has been presented by Garden (1986). A map of the H_2 1–0 S(1) line, at 2.12 μm, in Orion was made with the UKIRT in January 1985 and obtained by frequency-switching a Fabry-Perot etalon (FP) with $\sim 130\,\mathrm{km\,s^{-1}}$ resolution. The aperture size was 19" and the map made by raster scanning the telescope on a 15" spacing grid. An area of $\sim 7' \times 9'$, and containing ~ 1000 pixels centred on the Trapezium star cluster, was covered and is shown in Figure 1. Figure 2 is an enlargement of the shocked region around OMC–1. The outermost contour (labelled 1 unit) corresponds to the 1σ detection limit, which is 7×10^{-21} W cm^{-2} per beam.

The total 1–0 S(1) line luminosity in the region mapped is $\sim 4.5\ L_\odot$. There are two basic components contributing to this luminosity; (a) a shocked component from the BN-KL region powered by an outflow from the source IRc2, and (b) a more extended, diffuse component from the Orion photodissociation region, powered by UV from the Trapezium star cluster. We now estimate the luminosity of each component.

From inspection of Figure 1, it can be seen that the level of the diffuse fluorescent component is about 8 units on the map, with a likely range from 6–10 units. If we subtract this background level from the shocked component (taken to cover a $3' \times 3'$ region centred on BN – see Fig. 2)), we obtain for the shocked 1–0 S(1) line luminosity (including emission from the molecular hydrogen reflection nebula) 2.5 $L_\odot$ (2.3 – 2.6 $L_\odot$; the range reflecting the range in uncertainty in the level of the background). The extinction at 2.1 μm to the shocked region is somewhat uncertain, but probably ~ 1 mag. (Brand *et al.* 1988). The fraction of the total shocked H_2 line emission emitted through the 1–0 S(1) line is $\sim {}^1/_{15}$ (Burton *et al.* 1988). Thus the total shocked H_2 line luminosity is estimated to be 94 [88 – 99] $L_\odot$.

The remaining S(1) line emission is fluorescently-excited. We estimate its luminosity to be 2.0 [1.9 – 2.2] $L_\odot$. This is a lower limit, but any additional contribution will likely be small; if we assumed a flux equal to the lowest contour on the map was emitted from a region extending 1 arcmin further in all directions, then the extra contribution will be about 10%. In a pure fluorescent source, the 1–0 S(1) line contributes $\sim 1.8\%$ of the total H_2 line emission (Black & van Dieshoeck 1987). Thus, adopting one magnitude of extinction as before (although the extinction will likely be less since it lies in front of the shocked region), we estimate that the total fluorescent H_2 line luminosity of Orion is $\sim 290[270 - 310]\ L_\odot$. This is greater than the total shocked emission from the source.

This fluorescent luminosity can be compared to models for the Orion photodissociation region (*e.g.*, Tielens & Hollenbach 1985). The total luminosity of the ionizing stars in the HII region is $\sim 10^5\ L_\odot$. Thus the efficiency, $L_{S(1)}$ / L_{Tot}, is $\sim 2 \times 10^{-5} \times 4\pi/\Omega$, where Ω is the solid angle subtended by the molecular cloud from the ionizing stars. For an UV-radiation field 10^5 times the ambient interstellar value (appropriate to the Orion PDR) and a gas density of $10^6\,\mathrm{cm^{-3}}$, this efficiency is calculated to be $\sim 4 \times 10^{-5}$ (Burton, Hollenbach & Tielens, 1989), while for a density $10^5\,\mathrm{cm^{-3}}$, the efficiency is $\sim 3 \times 10^{-6}$. Thus the fluorescent S(1) line luminosity is consistent with model predictions for high density photodissociation regions.

Conclusions

The H_2 1–0 S(1) line luminosity from the shocked and fluorescent emitting regions of Orion have been estimated to be 2.5 and 2.0 $L_\odot$, respectively. Thus, although the peak line flux from the shock is 100 times the diffuse component, the integrated fluorescent emission is comparable to the shocked component. The total fluorescent emission through all lines is estimated to be $\sim$ 300 $L_\odot$, roughly three times the total shocked emission. Therefore when using Orion as a standard candle to study the ISM of galaxies, it is important to consider both the fluorescent and the shocked contributions to the emission.

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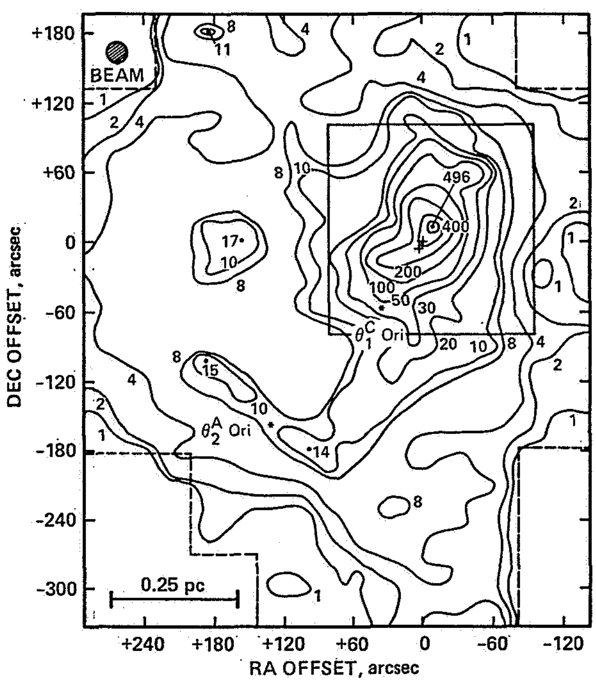

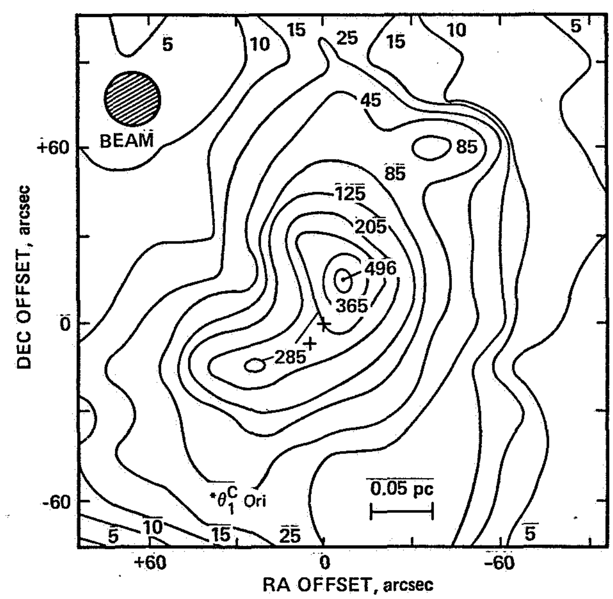

Figure 1. (left) Contour map of the H_2 1–0 S(1) line emission from Orion. The map is centred on the BN source. Contour levels are in multiples of the lowest contour, which corresponds to a line flux of 7×10^{-21} W cm^{-2} through a 19" aperture. The crosses denote the IR sources BN (upper right) and IRc2 (lower left). The optical stars θ_1^C Ori and θ_2^A Ori are denoted by the $*$s. The dashed line defines the region observed.
Figure 2. (right) Enlargement of the region included in the box of Figure 1, showing the shocked emission region around OMC–1.