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Probing Collimated Outflows from Post-AGB Stars with H_2

Kieran Forde

CAR/STRI, University of Hertfordshire, College Lane Campus, Hatfield, AL10 9AB, UK

T.M. Gledhill, M.D. Smith

We present an analysis of the H_2 molecular excitation and shaping mechanisms of the circumstellar envelope (CSE) of IRAS 16594–4656, using VLT/SINFONI *K*-band integral field spectroscopy. We detect several collionally excited H_2 emission lines, *i.e.*, the H_2 traces the shock-front produced by the interacting winds. In this wavelength range post-AGB objects with H_2 can display several ro-vibrational emission lines. We use this H_2 emission to form line maps and line-ratio maps to distingush between shock and fluorescent excitation. The line ratios also allow us to determine the ortho-to-para ratio and rotational/vibrational temperatures for this object. We calculate a 1-0/2-1S(1) ratio of ≈19 at various locations across the object. A comparison of several vibrational lines permitted a rotational temperature of ≈1400 K to be estimated. Using these observed values as constraints, we use magneto-hydrodynamic planar shock models to determine properties of these stellar outflows such as magnetic field strength, gas densities, and shock velocities, which are otherwise difficult to measure. We find that a fast wind impacting the slower moving post-AGB outflow of density 10^7 cm^{-3} drives the H_2 excitation via shocks with a velocity of ≈20 km s^{-1}, while the Br-γ emission is confined to the region directly around the central star. In order to fully match shock models to our observations, an extensive grid of models covering all variable parameters is required. It might be the case that more complex models are required, *i.e.*, planar shocks are not representative of the type of shock recorded in IRAS 16594–4656.

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Kieran P. Forde, Tim M. Gledhill, Michael D. Smith
E-mail: k.forde@herts.ac.uk

Context

The debate to resolve why the initially spherical circumstellar envelope (CSE) gets distorted into a multitude of axisymmetric structures is ongoing. Although, it is clear that the shaping process occurs near the end of the AGB phase or start of the post-AGB phase. In the near infrared some post-AGB stars display H_2 in emission — the temperature of the star is not high enough to ionise the surrounding molecular cloud allowing the H_2 to emit via quadrupole ro-vibrational transitions. We use this H_2 emission to investigate the possible cause of the excitation, i.e., is a shock or fluorescent mechanism responsible. Collisionally excited H_2 will trace the interaction between the fast post-AGB wind and the previously detached slower AGB envelope, yielding information on the possible shaping processes at work. Previous work, e.g., [1] used longslit spectroscopy and/or imaging to study these objects, we intend to:

- use integral field spectroscopy (IFS) techniques to analyse H_2 emission in a range of post-AGB objects,
- determine the underlying excitation mechanisms,
- use our observations to constrain the shock models.

Data Acquisition

The data was obtained using the SINFONI instrument on the VLT/UT4 telescope in conjunction with the AO system. SINFONI is a near-infrared IFS fed by adaptive optics module. All observations were taken using the *K*-band grating with a resolution of R∼4000, and all data have a FOV of 3"×3".

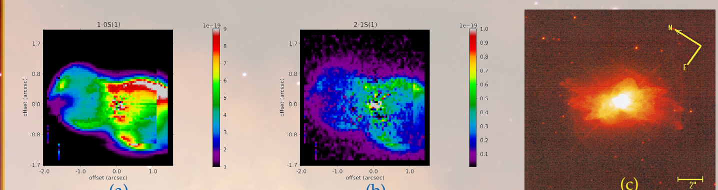
Summary

We present an analysis of the H_2 excitation and shaping mechanisms of the CSE of IRAS 16594-4656. We detect several collisionally excited H_2 emission lines. We use the H_2 emission to distinguish between shock and fluorescent excitation. We calculate a 1-0/2-1S(1) ratio of $\sim$ 19, a rotational temperature of $\sim$ 1400 K, and an ortho-to-para ratio (OPR) of $\sim$ 3.3 at various locations across the object. Using these observed values as constraints, we use magneto-hydrodynamic planar shock models [2] to determine properties of these stellar outflows such as, magnetic field strength, gas densities, and shock velocities, which are otherwise difficult to measure. We find that a fast wind impacting the slower moving post-AGB outflow of density 10^7 cm^{-3} drives the H_2 excitation via shocks with a velocity of $\sim$ 20 km s^{-1}. Figure (e) shows that the temperature does not vary across the FOV which indicates that a C-shock might be responsible for the excitation; supported by the fact that a *J*-shock would produce more 3-2S(3) emission than is detected. [3] detect centrally located [FeII] in IRAS 16594-4656 suggesting that two types of shock might be at work — a *J*-shock for the [FeII] and a C-shock further out impacting at angles to the H_2 along the cavity wall.

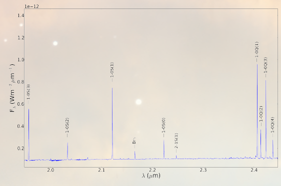
References

[1] Van de Steene, G. C., et al., 2003, A&A, 406, 773-781
[2] Smith, M. D., 1994, MNRAS, 266, 238-+
[3] Van de Steene, et al., 2008, A&A, 480, 775-783
[4] Hrivnak, B. J., et al., 1999, ApJ, 524, 849-856

IRAS 16594-4656



(a) (b) (c)

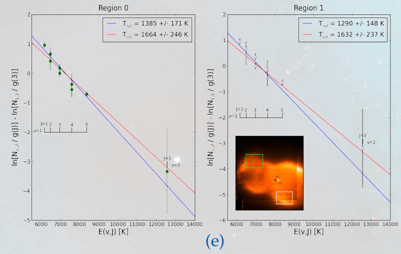


(d)

The *K*-band hosts a multitude of strong H_2 emission lines. Figures (a) and (b) above show the spatial extent of the 1-0 & 2-1S(1) H_2 line emission for IRAS 16594-4656, respectively (north is up, east is left). These lines can be used to discriminate between types of excitation mechanisms. Figure (c) shows an optical *HST* image of IRAS 16594-4656 [4] displaying a multi-polar morphology in contrast to the the *K*-band line maps which show it is strongly bipolar. All lines detected are presented in Figure (d) for IRAS 16594-4656.

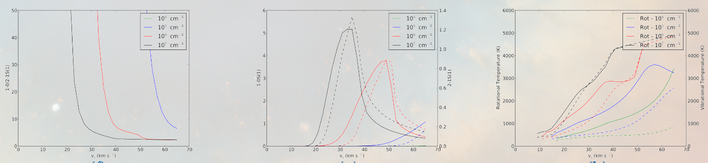
Results

We present some results from the analysis of the VLT IRAS 16594-4656 *K*-band datacube.



(e)

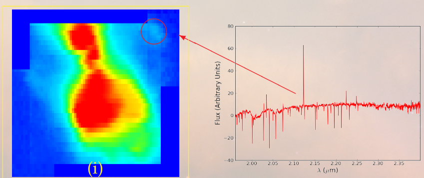
Two estimates of temperature can be made once the reddening-corrected line strengths are known, a rotational and a vibrational temperature. Figure (e) shows the temperature fits for two separate regions of IRAS 16594-4656; the regions extracted from the line maps to calculate these temperatures are indicated on the inset line map.



(f) (g) (h)

Figures (f), (g), & (h) explore how the 1-0/2-1S(1) line ratio, the 1-0S(1) & 2-1S(1) line flux, and the rotational & vibrational temperatures change with shock velocity, over several densities, using planar C-shock models. It is clear that only in a dense gas (10^7 cm^{-3}) can both vibrational and rotational temperatures be similar [see Fig. (h)]. In the case of IRAS 16594-4656 this temperature would correspond to a shock velocity of $\sim$ 20 km s^{-1}; Figure (f) shows this velocity would yield a 1-0/2-1S(1) ratio of $\sim$ 19 which is consistent with our observations.

OH 231.8+4.2



(i)

A recent observing run at VLT with SINFONI allowed us to extend our sample of post-AGB objects with H_2 emission to cover a range of evolutionary/spectral phases (M → B type). In the case of OH231.8 [see Fig. (i)], we detect equatorial H_2 located far from the object.

Acknowledgements

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