Probing the center of the canonical YSO L1551 IRS 5 – what we have learned from ISO, and the implications for FIRST science

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Spectroscopic observations using the Infrared Space Observatory are reported towards the two well known infrared sources and young stellar objects L1551 IRS 5 and L1551 ,NE, and at a number of locations in the molecular outflow. The ISO spectrum contains several weak gas-phase lines of OI, CII, [Fe,II] and [SiII], along with solid state absorption lines of CO, CO_2, H_2O, CH_4 and CH_3OH. Hubble Space Telescope (HST) images with the NICMOS infrared camera reveal a diffuse conical shaped nebulosity, due to scattered light from the central object, with a jet emanating from L1551 IRS 5. The continuum spectral energy distribution has been modelled using a 2D radiative transfer model, and fitted for a central source luminosity of 45 solar luminosities, surrounding a dense torus extending to a distance of ~ 3 10^4 AU, which has a total mass of ~ 13 solar masses. The visual extinction along the outflow is estimated to be ~ 10 and the mid-plane optical depth to L1551 IRS 5 to be ~ 120.

This model provides a good fit to the ISO spectral data, as well as to the spatial structures visible on archival HST/NICMOS data, mid-IR maps and sub-millimetre radio interferometry, and to ground-based photometry obtained with a range of different aperture sizes. On the basis of the above model, the extinction curve shows that emission at wavelengths shorter than ~ 2 µm is due to scattered light from close to L1551 IRS 5, while at wavelengths > 4 µm, is seen through the full extinguishing column towards the central source. Several [FeII] lines were detected in the SWS spectrum towards L1551 IRS 5. Although it would seem at first sight that shocks would be the most likely source of excitation for the [FeII] in a known shocked region such as this, the line intensities do not fit the predictions of simple shock models. An alternative explanation has been examined where the [FeII] gas is excited in hot (~ 4000 K) and dense (> 10^9 cm^{-3}) material located close to the root of the outflow. The SWS observations did not detect any emission from rotationally excited H_2. Observations with United Kingdom Infrared Telescope (UKIRT) of the vibrationally excited *S*- and *Q*-branch lines were however consistent with the gas having an excitation temperature of ~ 2500 K. There was no evidence of lower temperature (~ 500 K) H_2 gas which might be visible in the rotational lines. Observations with UKIRT of the CO absorption bands close to 2.4 µm are best fit with gas temperatures ~ 2500 K, and a column density ~ 6 10^{20} cm^{-2}. There is strong circumstantial evidence for the presence of dense (coronal and higher densities) and hot gas (at least 2500 K up to perhaps 5000 K) close to the protostar. However there is no obvious physical interpretation fitting all the data which can explain this.

The paper will attempt to draw together data from the complete wavelength coverage available from space and the ground, and summarise this in terms of what we might expect to learn from sources like this, that will be useful in planning the science programme for FIRST.