A Search for Infrared Positronium Line Emission from the Great Annihilator near the Galactic Centre

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Abstract.

The region around the compact source of 511keV gamma rays near the Galactic Centre (the "great annihilator") has been surveyed for the positronium recombination line emission expected to be produced by positron-electron systems before annihilation. The search was performed using the CGS4 spectrometer on UKIRT and centered on the 2.18μm line which is analogous to the Paschen gamma transition of hydrogen. Upper limits to the line flux and positron production rate are given.

1. Background: The Positronium Spectrum and the Galactic Centre

Positronium (Ps) is formed by the recombination of an electron and positron. The Ps wave function and energy levels are analogous to hydrogen once the mass is replace by $(m_e/2)$, the reduced mass of the system. If e^+ and e^- recombine in an excited state then they will cascade down through the energy levels radiating photons with wavelengths twice those of the corresponding hydrogen transitions (e.g. Ps(Hα) at 1.3126μm and Ps(Brγ) at 4.332μm) since the radiative lifetime is shorter than the annihilation lifetime. Eventually the 'atom' reaches the ground state followed by annihilation into two 511keV gamma rays or three 0-511 keV photons. (By analogy to helium there are both singlet and triplet systems because of the two 'electrons'; the triplet system is forbidden from two-photon decay).

The 511keV gamma ray line was first detected from the Galactic Centre region in the 1970s (e.g. Leventhal & MacCallum 1982) and is known from subsequent studies to undergo outbursts with the line flux varying by up to an order of magnitude (e.g. Leventhal et al. 1986, Leventhal et al. 1989). Increasingly high angular resolution observations have shown the enigmatic object 1E1740.7–2942 to be identified as the dominant source of hard X-rays and soft gamma rays in this region (e.g. Skinner et al. 1991). Radio measurements with the VLA have shown a double-sided radio source to be coincident with the high energy source and for the radio and hard X-ray fluxes to be correlated (Mirabel et al. 1992). Misra & Melia (1993) have modeled the lobe emission as synchrotron radiation from e^+ and e^- shock acceleration within the outflow.

Mirabel et al. (1991) and Bally & Leventhal (1991) have observed CS and HCO+ emission from a molecular cloud coincident with 1E1740.7 and proposed this as the fuel source for the emission mechanism. Moreover the cool molecular cloud might act to slow the relativistic particles (by Bremsstrahlung or collisional ionization) to the thermal velocities required for Ps formation. No near-infrared counterpart to 1E1740.7 has been detected in H (1.65μm) or K (2.2μm) imaging surveys of the field (Skinner 1992, personal communication; Haller & Melia 1994). Previous radio recombination line searches for Ps near the galactic centre have also been unsuccessful (Anantharamaiah et al. 1989).

2. Near-IR Spectroscopic Observations

Although no near-IR counterpart to 1E1740.7 has been detected in broadband imaging surveys, the possibility remains of detecting a narrow line source with a recombination spectrum. Therefore a spectroscopic search was made on 1993 April 5 using the facility cooled grating spectrometer (CGS4) on UKIRT.

The 3 arcsec-wide slit was centred on the radio continuum core [RA(1950)= $17^h40^m43.01^s$, δ(1950)=-29° $43'$ $25.5''$ with a position angle aligned along the radio jets (161.1° E of N). The 150 l/mm grating (R=1400) was centred on the Ps Paschenγ transition at 2.18μm. The telescope was nodded to random positions between 10 and 40 arcsec away from the nominal position with an integration time of 4$\times$20s at each position for a total on-source integration time of 800s. Wavelength calibration was performed using a Krypton arc lamp and the star BS6494 (B9IV) was observed before and after 1E1740.7 to provide atmospheric calibration. This was assumed to have K=6.0, based on its visual magnitude V=6.0, for the purpose of flux calibration.

The field in which 1E1740.7 lies contains a great many near-IR sources (e.g. Haller & Melia 1994). Consequently each object and sky position of the slit contained several, typically 1 to 3, unwanted continuum objects. The usual technique for reducing imaging data of such fields, that of forming a background frame by median filtering a number of offset images, was found not to be particularly useful in this instance because of the residual telluric OH line emission. Instead, averages of the object minus sky positions were formed from groups of eight adjacent frames with each group having residual OH lines removed by fitting perpendicular to the dispersion direction and continuum sources removed by fitting a low order polynomial along the spectrum. The final frame was formed from the average of these groups.

3. Discussion

Figure 1 shows the flux calibrated spectrum extracted from the position corresponding to the core radio source. No line emission is apparent in the data which is not attributable to noise, nor at any other position along the slit. The noise is significantly greater than that theoretically achievable with this instrument because of the surface density of sources and telluric OH emission which varied appreciably during the course of the observation. Indeed the Ps Paγ line lies very close in wavelength to one of the brighter lines in the OH spectrum, as can be seen in the raw sky spectrum in Figure 2.

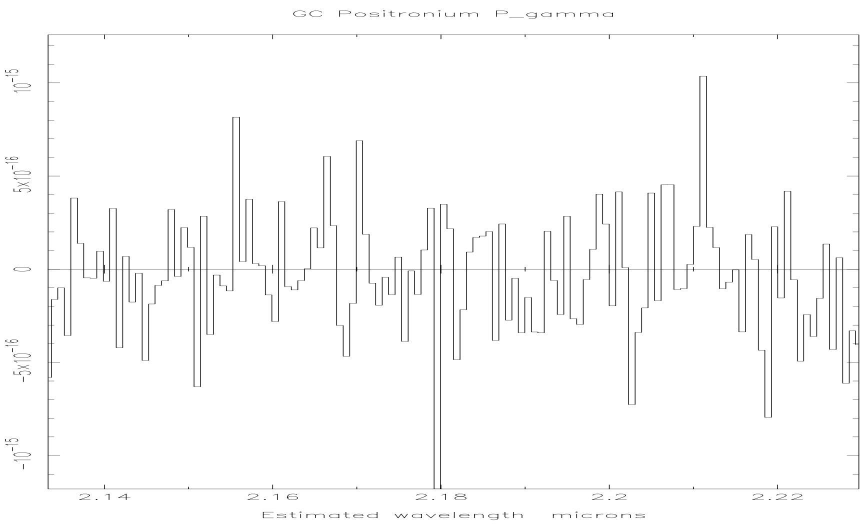

Figure 1. Spectrum around the Ps Paγ ($\lambda 2.18\mu$m) line at the position of the core radio continuum source. The flux density units are $\mathrm{Wm}^{-2}\mu\mathrm{m}^{-1}$. No significant spectral features other than residual telluric OH emission are apparent.

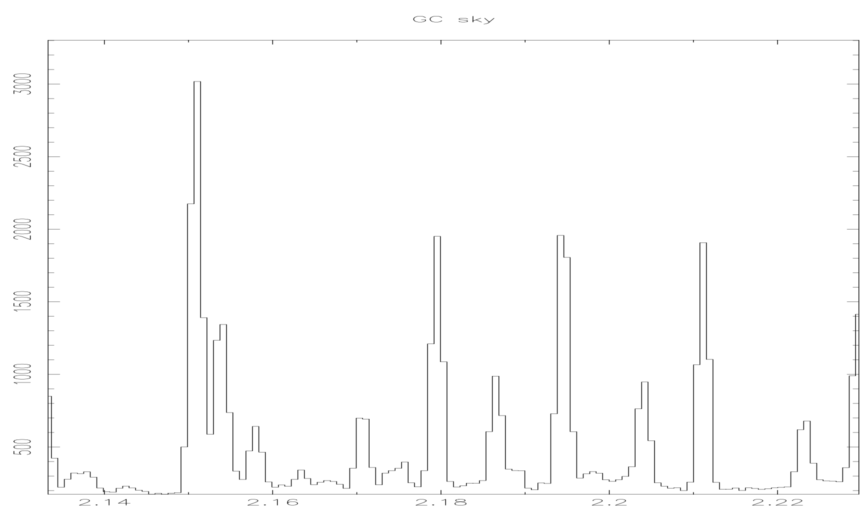

Figure 2. Spectrum of the night sky taken from the Ps dataset (arbitary units). The wavelengths of strong telluric OH lines correlates with residual features in the Ps spectrum (Figure 1).

The average noise level in the Ps spectrum corresponds to a 3σ upper limit for an unresolved line of 3×10^{-19} Wm^{-2}. At a distance to the Galactic centre of 8.5kpc, this corresponds to a Paγ production rate of less than 3×10^{42} s^{-1}, which increases to 6×10^{43} s^{-1} if we assume an extinction to the source of $A_K = 3$mag. This upper limit corresponds to the positron production rate if the (over)simplification is made that all recombinations pass through the Paγ transition and may be compared with the upper limit from Anantharamaiah et al. (1989) of $< 3.1 \times 10^{43}$ s^{-1}, and the flux estimated from the 511keV detection in outburst of 4×10^{43} s^{-1}.

Our new IR spectroscopy cannot place any additional constraints on the Ps emission mechanism however the limits are approaching the expected flux level. We believe that the prospect for observations at the higher angular resolution and collecting area of forthcoming 8m class telescopes such as Gemini and the VLT is promising.

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