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A Very Extended Ionized Nebula around the Quasar MR2251-178

P. L. Shopbell, S. Veilleux

Department of Astronomy, Univ. of Maryland, College Park, MD 20742
pls@astro.umd.edu, veilleux@astro.umd.edu

J. Bland-Hawthorn

Anglo-Australian Observatory, P.O. Box 296, Epping, NSW 2121
jbh@aaoepp2.aao.gov.au

Abstract. We report the results of deep emission-line (Hα) imaging of the ionized gas surrounding the low-redshift (z = 0.0638) quasar MR 2251–178 using the Taurus Tunable Filter on the AAT telescope. Our observations detect ionized gas out to a radius of 120 kpc, the deepest detection yet in this system. The total mass of ionized gas is 6×10^{10} $M_{\odot}$ (upper limit). The large and symmetric extent of the gaseous envelope favors a model in which the filamentary and diffuse emission arises from a large cloud complex, photo-excited by the bright quasar. A crude kinematic analysis does not support an origin for the gas in an interaction with the nearby galaxy G1. We conclude that significant quantities of ionized gas in the galactic environment may go undetected with current observational techniques.

1. Introduction

Recent advances in instrumentation have lead to a number of detections of diffuse, extended ionized gas outside of the standard galactic environment; for example, the extended disks of spiral galaxies (Bland-Hawthorn *et al.* 1997) and clouds in the Magellanic Stream (Weiner & Williams 1996). One particularly successful area of observation has been that of extended stellar and gaseous components surrounding radio-quiet and radio-loud active galaxies and quasars (e.g., Stockton & MacKenty 1987; Tadhunter *et al.* 1994; Hutchings *et al.* 1999). While these components vary greatly in both extent and morphology, the observations suggest that this material may be present in substantial quantities around such systems.

Traditional deep narrowband observations are expensive, in terms of both telescope time and monetary cost for interference filters for modern large-beam telescopes. In order to circumvent this, Fabry-Perot spectrometers are now being employed in a "stare mode" to detect diffuse emission-line gas over small fields and narrow wavelength regions. In this paper, we present deep Hα observations of the extended ionized gas surrounding a quasar, MR 2251–178, using a new, etalon-based instrument which has been optimized for the detection of faint, extended emission-line gas, the Taurus Tunable Filter (TTF)[1]. The flexibility of this instrument provides essentially monochromatic imaging at an arbitrary wavelength and bandpass. The high efficiency and tunable nature of the TTF allow the acquisition of multiple images at a range of wavelengths, providing kinematic information as well.

2. Observations

First discovered as a strong and variable X-ray source (Cooke *et al.* 1978), MR 2251–178 was subsequently identified as a quasar at a redshift of 0.0638 (Canizares *et al.* 1978). Optical imagery and spectroscopy have detected two ionized gas components around the quasar: an elongated, highly-ionized circumnuclear component of diameter ~ 27 kpc, and an extended envelope of faint Hα- and [OIII]-emitting filaments out to a radius of ~ 110 kpc (e.g., Bergeron *et al.* 1983; Macchetto *et al.* 1990). Spectroscopic observations have determined that the extended ionized gas component, while undoubtedly associated with the quasar, is not following its rotation pattern (Nørgaard-Nielsen *et al.* 1986; Mulder & Valentijn 1992).

Figure 1 presents our Hα imagery of MR 2251–178. In the discussion that follows, we assume $H_0 = 50$ km s^{-1} Mpc^{-1} and a corresponding image scale of 1.9 kpc arcsec^{-1}.

2.1. Morphology

Our observations detect Hα emission throughout the central arcminute of the field. We confirm two primary ionized gas components in MR 2251–178: The first consists of strong Hα emission directly surrounding the quasar out to a radius of ~ 20 kpc, slightly elongated along the axis of the quasar's radio jet (PA $\sim 102°$; Macchetto *et al.* 1990). This component has been identified as an "extended emission-line region" (EELR) of the quasar host galaxy (Mulder & Valentijn 1992).

The second Hα component consists of a much larger network of filamentary emission. Diffuse emission is visible surrounding the galaxy on all sides, out to a radius of at least 50 kpc; knots and filaments of ionized gas are visible to radii up to 120 kpc towards the northeast, southeast, and southwest. The morphology of the filaments is very similar to that of spiral arms, with an "arm" clearly visible in each of these three directions. This remarkable symmetry has not been seen in previous, i.e., less deep, imaging observations.

2.2. Kinematics

Comparison of imagery at two separate redshifts (panels *a* and *b* of Figure 1) reveals a broad velocity gradient across the quasar nebula (PA $\sim 40°$). The eastern filaments are generally less redshifted than the western filaments and represent the only gas possibly near the systemic velocity of the quasar. The western filaments in the "red" image appear to be redshifted from the systemic

[1]Consult Bland-Hawthorn & Jones (1998, PASA, 15, 44) and the TTF web page for further details on the instrument: `http://www.aao.gov.au/local/www/jbh/ttf/`.

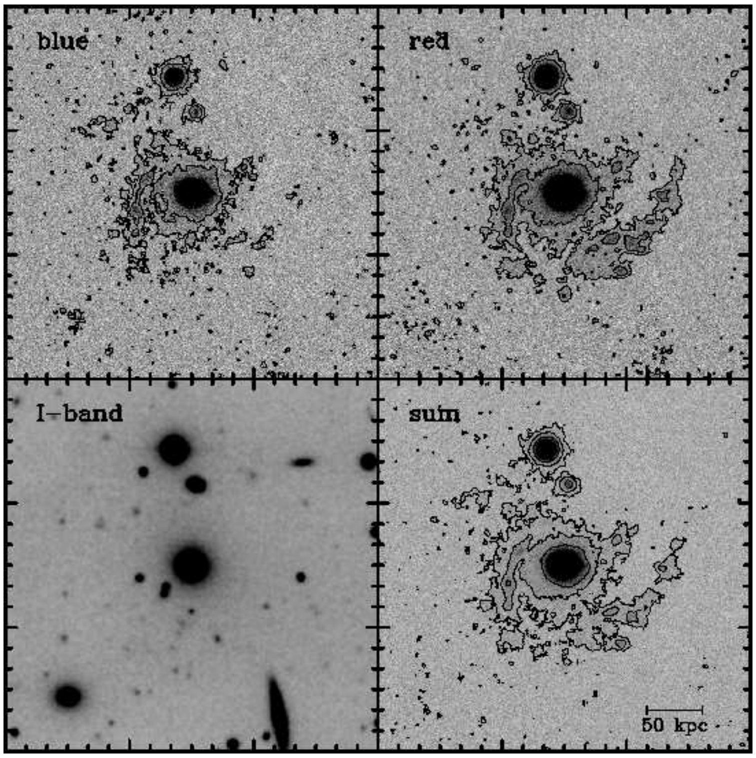

Figure 1. Deep imagery of the field surrounding the quasar MR 2251–178. Panels *a* and *b* are 1200 second exposures of Hα at redshifts of 0.0640 and 0.0645, respectively. Panel *c* is an I-band continuum image of the same field, illustrating a number of galaxies in the cluster. Panel *d* is a summed Hα image. All panels are $3'$ in size, with north up and east to the left.

velocity by a value of $\sim 200 - 300$ km s^{-1}. The clear difference between the filament morphologies in the blue and red images - particularly in the northeast and the west - implies that essentially all of the detected emission is redshifted relative to the quasar. These conclusions agree well with the published spectroscopic observations of Nørgaard-Nielsen *et al.* (1986). We also confirm that the velocity structure of the extended ionized gas component does not appear to follow the rotation curve of the quasar (Bergeron *et al.* 1983).

2.3. The Mass of the HII Envelope

We derive a total flux from the extended filaments of 1.4×10^{-13} erg cm^{-2} s^{-1}. This implies a luminosity of 2.5×10^{42} erg s^{-1} at the redshift distance of the quasar (384 Mpc). Assuming complete ionization and employing a geometry in which the filaments are approximately as deep as they are wide (i.e., 7 pixels $\sim$ 5 kpc), we calculate an rms filament density of $\langle n_e \rangle \sim 0.04 \cdot f^{-1/2}$ cm^{-3}. For a filling factor $f = 1$, this implies an upper limit on the ionized gas mass of $M \sim 6 \times 10^{10}$ M$_\odot$, distributed in a volume of 6.1×10^4 kpc^3. These estimates are consistent with previously published values (Nørgaard-Nielsen *et al.* 1986; Macchetto *et al.* 1990).

3. The Origin and Ionization of the HII Envelope

Our observations reveal a tremendous spatial extent for the emission in this system. We also observe a relatively high degree of symmetry in the envelope, including at least three "arms" of ionized gas. This symmetry, together with the organized large-scale kinematics, does not support an interaction model for creation of the ionized gas. The fact that galaxy G1 ($v_r = +1246$ km s^{-1} relative to MR 2251–178) is positioned just north of the quasar, amongst relatively blueshifted filaments, strengthens this argument. Nevertheless, the coarse kinematic structure of the extended ionized gas indicates that it represents a distinct component from the inner counter-rotating EELR, suggesting that the envelope most probably did not originate within the quasar and/or host galaxy. Our observations appear to favor a model in which the extended ionized envelope resides within a large complex of HI gas centered about the quasar.

The source of the ionization of the extended component is difficult to constrain with our limited spectral information. Again, the relative symmetry of the envelope in our observations virtually eliminates ionization mechanisms associated with the quasar jet (PA $\sim 102°$; Macchetto *et al.* 1990). One could conceive of a small population of in-situ hot stars which would provide sufficient ultraviolet flux to ionize the gas yet be faint enough to avoid detection in broadband observations (Macchetto *et al.* 1990). However, a significant amount of *diffuse* ionized gas is present in the nebula, suggesting an exterior ionization source. More importantly, the deep R-band imagery of Hutchings *et al.* (1999) exhibits a faint component extended along the N–S direction, markedly different from the NE–SW axis along which we observe strong emission in Hα. They do not detect an excess of continuum emission at the locations of any of the brighter Hα knots in the envelope. We therefore concur with previous authors that the primary source of gas excitation is probably the quasar itself.

In summary, our Hα observations of MR 2251–178 demonstrate that significant quantities of ionized gas may be present around luminous quasars at flux levels virtually undetectable by standard narrowband imaging techniques. The TTF promises to greatly impact such observational programs by increasing the depth to which diffuse line emission can be detected by a factor of at least 5–10.

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