High Resolution Spectroscopy of SN1987A’s Rings: He I \( \lambda 10830 \) and H\( \alpha \) from the Hotspots

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Abstract.
We present the first high-dispersion spectroscopy of He I \( \lambda 10830 \) from the hotspots in the ring around SN1987A, obtained at Gemini South, spatially resolving the near and far sides of the ring. We compare these line profiles to similar echelle spectra of H\( \alpha \) and [N II] \( \lambda 6583 \) obtained at the Magellan Observatory. We find that the He I profiles are much broader than H\( \alpha \) or [N II], but the He I profiles also have different shapes – they have enhanced emission at high speeds, with extra blueshifted emission on the north side of the ring, and extra redshifted emission on the south side. To explain this, we invoke a simple geometric picture where the extra He I emission traces hotter gas from faster shocks that strike the apex of the hotspots directly, while the H\( \alpha \) preferentially traces cooler lower-ionization gas from slower transverse shocks that penetrate into the sides of the ring.

Keywords: supernovae; supernova remnants; SN 1987A

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INTRODUCTION

Twenty years after the explosion, the blast wave from SN1987A has now reached and is plowing through the circumstellar ring. Protrusions caused by Rayleigh-Taylor instabilities in the ring were hit first by the blast wave, giving rise to a series of “hotspots” around the ring [2,5,6]. The interaction has three different velocity components:
1. Extremely broad (–15,000 to 15,000 km s\(^{-1}\)) emission in H\( \alpha \) and Ly\( \alpha \) that traces H atoms crossing the reverse shock. This can be seen in low-resolution spectra [4]. One sees blueshifted emission to the north, and redshifted emission to the south, like the expansion pattern of the ring itself [1].
2. Broad (few \( 10^2 \) km s\(^{-1}\)) components emitted by gas in the ring that has been passed over by the forward shock [2,3]. This is the emission from the “hotspots”.
3. Narrow (10’s of km s\(^{-1}\)) emission lines from slow-moving gas in the circumstellar ring that has not yet been reached by the shock, but is photoionized by UV emission from the shock interaction [3].

Here we concentrate on the spatially resolved emission-line profiles of the shock-heated gas in the hotspots on the north (near) and south (far) sides of the ring, seen in H\( \alpha \) and He I \( \lambda 10830 \).

Observations: We present high resolution (R=60,000) ground-based spectra of the inner equatorial ring of SN 1987A. We used the Phoenix spectrograph on Gemini South to observe He I \( \lambda 10830 \) in Apr 2006, with the 0.5” slit oriented as in Fig. 1. These long-slit data spatially resolved the north and south sides of the ring (Fig. 1a). We also used the MIKE echelle spectrograph at the Magellan Observatory to obtain the optical...
spectrum in March 2005. The 2-D spectrum of Hα is shown in Fig. 1b. Tracings of the north and south sides of the rings are shown in Figures 1c and d, respectively, for both lines as well as [N II] λ6583. The [N II] line has stronger narrow emission from unshocked circumstellar gas, and is scaled up to show that the profile of its broad shocked component is identical to Hα.

LINE PROFILES AND GEOMETRY OF HOTSPOT EMISSION

In the scenario depicted in Figure 2, we can understand the difference in line profile shape between He I λ10830 and Hα as a consequence of ionization levels, geometry, and shock kinematics. When the expanding blast wave encounters an obstacle like an equatorial ring, with or without a protruding “finger” from Rayleigh-Taylor instabilities, the shock will penetrate the dense material head-on and decelerate, but it will also wrap around the object, transmitting weaker and slower oblique shocks into the sides of the obstacle (see Fig. 2). The denser, cooler, slower, and lower-ionization gas in these oblique shocks probably dominates the Hα and broad [N II] emission [3]. This will produce broad emission at both blue and redshifted velocities. He I λ10830 emission will arise in this same gas, but it is also likely to be enhanced relative to Hα in the
hotter and higher ionization gas at the head of the shocked column. If true, that would in principle explain the observed line profiles, because that gas would have higher projected speeds on both the blue and red sides of the ring (Fig. 2) than the circumstellar gas struck by the oblique shocks in the side of the column, as observed (Fig. 1).

The enhanced He I emission at the end of the shocked column, plus the weakness of the narrow He I emission from unshocked gas (less than 5% of the total) means that He I λ 10830 images of the hotspots [6] are among the best tracers of the strong shocks in the circumstellar gas. A comparison of variability between Hα and He I in high-resolution images might provide important clues about the geometry of the shock front. If the “fingers” that are being illuminated by the shock at the present time to produce the hotspots really are the inner protrusions from a more massive ring, then we should expect the ring to brighten dramatically in the near future in He I λ 10830 as this more extended material is overtaken by the main blast wave.

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