THE ASTROPHYSICAL JOURNAL, 389:L25–L28, 1992 April 10

G203.2−12.3: A NEW OPTICAL SUPERNOVA REMNANT IN ORION

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Received 1991 August 6; accepted 1992 January 29

ABSTRACT

We report the discovery of what appears to be a supernova remnant at unusually high latitude near the Galactic anticenter. CCD images in the light of both [S II] and Hα show patchy filaments scattered over a 3′ region, but with relative strengths in the two lines which vary by a factor of 20 from one filament to another. Spectra confirm the line identifications and variable intensities. The most extreme filaments have line flux ratios [S II]/Hα ≈ 5, among the highest observed in remnants. The position of G203.2−12.3 coincides with that of a "guest star" recorded by Chinese astronomers in A.D. 483.

Subject headings: supernovae: general — supernova remnants

1. INTRODUCTION

We report here our discovery of a network of filamentary nebulosity, approximately 3′ in extent and located in Orion, in the general direction of the Galactic anticenter. Our narrowband CCD images show a morphology which strongly suggests a supernova remnant (SNR). Spectra of the filaments show that most of them have high [S II]/Hα ratios, $I(6716, 6731)/I(\mathrm{H}\alpha) \gtrsim 0.4$, characteristic of cooling material behind a shock and typical of SNRs (Dopita et al. 1984; Fesen, Blair, & Kirshner 1985). A few of the brightest filaments, however, have [S II]/Hα $\lesssim 0.2$, more characteristic of photoionized material. The nebulosity we discuss here is barely visible on the red Palomar Sky Survey plate. We have found no reference to any nonstellar object within 10′ in the numerous catalogs of SNRs, H II regions, planetary nebulae, *IRAS* sources, etc., which are included in the SIMBAD astronomical data base, or in the compilation of Dixon & Sonneborn (1980). As we discuss in § 3, however, ancient Chinese records indicate what may have been a supernova in A.D. 483 near the site of G203.2−12.3.

2. OBSERVATIONS AND RESULTS

2.1. *Imagery*

The object which we shall refer to as G203.2−12.3 was first noted on a deep red plate obtained at the ESO 1 m Schmidt telescope as part of a program to search for Herbig-Haro objects in the Orion region. The existence of filamentary nebulosity in this region was confirmed through CCD images obtained at the ESO 3.6 m telescope. Subsequent imaging observations were carried out from the 2.5 m du Pont telescope of the Las Campanas Observatory on 1991 January 15, using the modular spectrograph in its imaging mode. The detector was the 1024 × 1024 pixel CRAF CCD, used with a 200 mm reimaging lens to cover a field 4′.9 square at 0″.29 pixel^{-1}. Interference filters were used to isolate emission lines of Hα, [S II], [O III], and a reference continuum band. Exposure information and characteristics of the filters are given in Table 1. (The "Hα" filter passes some emission in the [N II] lines λλ6548, 6583, but, since our spectroscopy indicates that the [N II] lines are generally weak compared with Hα, we refer to this band simply as Hα.)

All the frames were corrected for sensitivity variations in the chip and minor vignetting, using a series of well-exposed dome flat-field frames and standard IRAF[3] procedures. Exposures of spectophotometric standard stars from Stone & Baldwin (1983) were used for flux calibration.

The Hα and [S II] frames are shown in Figures 1*a* and 1*b* (Plate L1). No nebulosity is visible in the [O III] frame (not shown). The nebulosity appears in Hα and especially in [S II] as a loosely organized network of rather delicate filaments extending over approximately a 3′ region, centered at $\alpha(1950) = 5^{\mathrm{h}}47^{\mathrm{m}}20^{\mathrm{s}}$, $\delta(1950) = +2°52'25''$ ($l = 203°.2$, $b = -12°.3$). This position is indicated in Figure 2 (Plate L2) along with four stars with coordinates given in Table 2 to facilitate astrometry of the filaments. Very faint emission is visible toward the edges of the 4′.9 field, suggesting a larger extent. Of well-studied Galactic SNRs, the one that appears most similar to G203.2−12.3 in morphology is RCW 89 (van den Bergh, Marscher, & Terzian 1973; van den Bergh 1978).

Significant differences in the relative strength of Hα and [S II] emission from filament to filament are apparent from Figure 1. The few features which are brightest in Hα include a flattened annulus, about 6″ × 12″ in extent, at the eastern edge of nebulosity, and a filamentary tail extending westward from the annulus some 20″. Peak Hα intensities in these features have values (15–20) × 10^{-16} ergs s^{-1} cm^{-2} arcsec^{-2}. Filaments which are most prominent in [S II] are generally somewhat fainter, but these are more widespread than the bright Hα features. Peak [S II] intensities for the brightest filaments in

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[3] IRAF is distributed by the National Optical Astronomy Observatories, operated by AURA, Inc., under contract with the National Science Foundation.

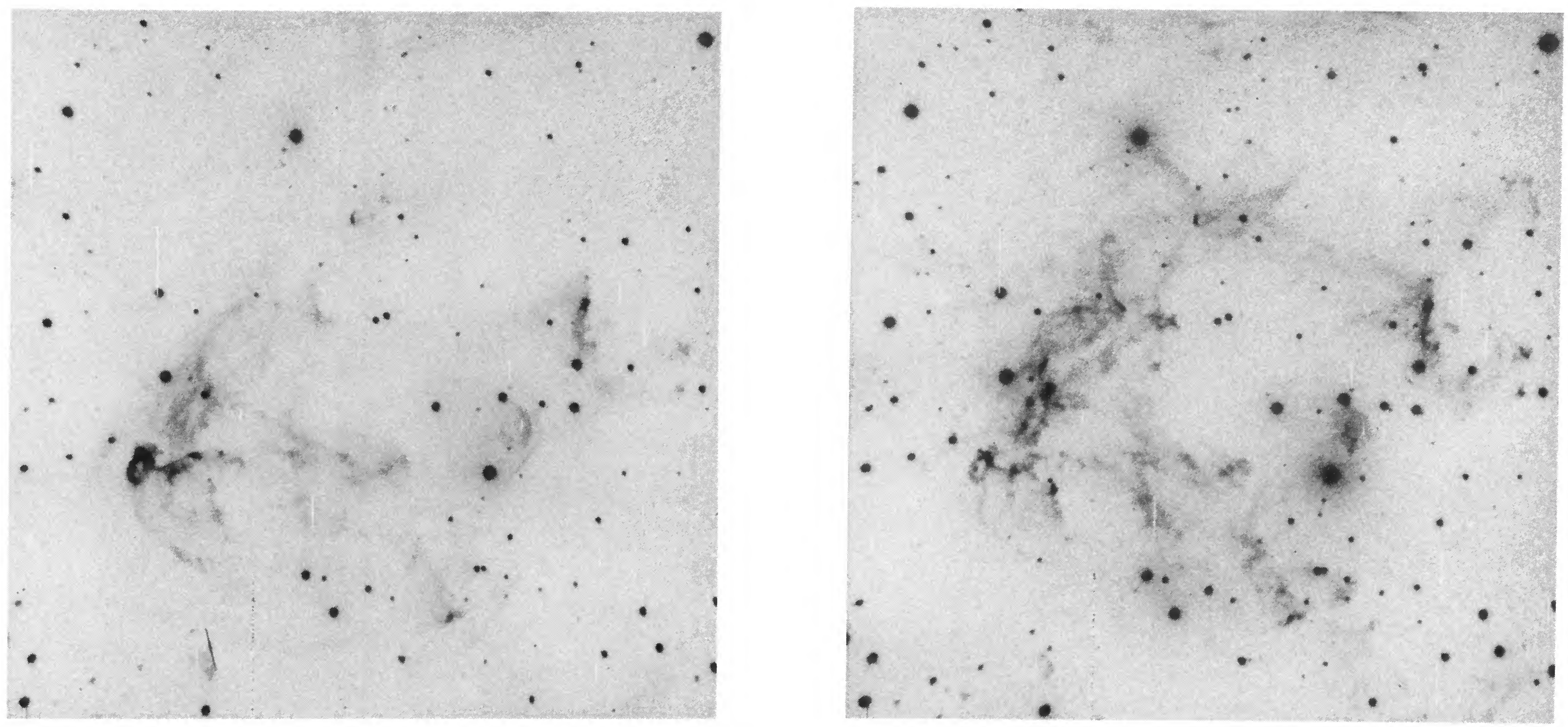

FIG. 1*a*   FIG. 1*b*

FIG. 1.—CCD image of the SNR G203.2−12.3 in the light of (*a*) Hα, and (*b*) [S II]. The field is 4'.9 square. The orientation is approximately north at top, east at left; see Fig. 2 for reference stars and accurate orientation. In this display the intensity scale is linear, with saturation values set at approximately 11×10^{-16} ergs s^{-1} cm^{-2} $arcsec^{-2}$ for Hα, and 5×10^{-16} ergs s^{-1} cm^{-2} $arcsec^{-2}$ for [S II].

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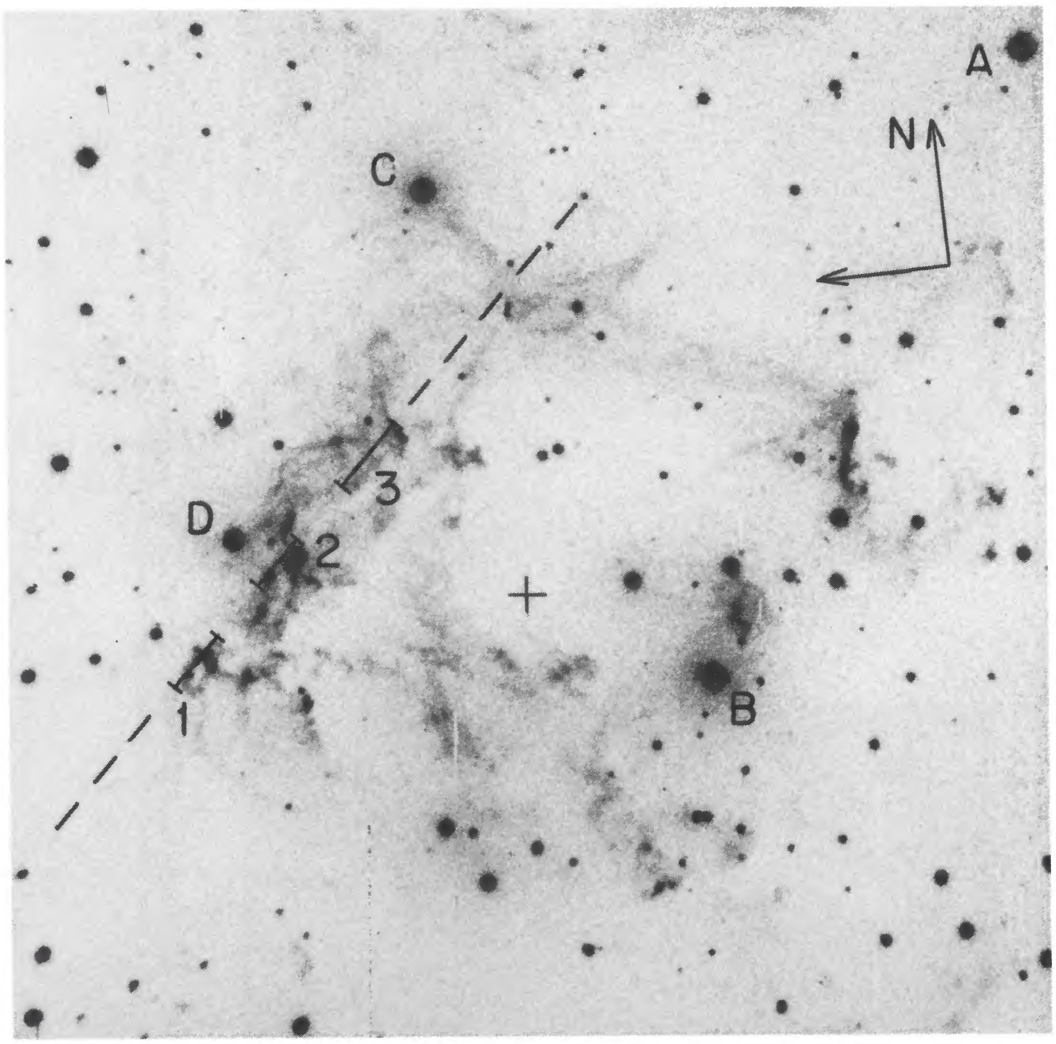

FIG. 2.—CCD image of the SNR G203.2−12.3 in the light of [S II] (same image as in Fig. 1*b*, but with reference stars and accurate directions of north and east indicated). See Table 2 for star coordinates. The plus sign indicates the nominal center of the SNR. The spectrograph slit location is also shown; one-dimensional spectra have been extracted at the positions denoted 1–3 along the slit.

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TABLE 1

DIRECT CCD EXPOSURES[a]

Name	λ_c (Å)	$\Delta\lambda$(FWHM) (Å)	T_{peak} (%)	Exposure (s)
Hα	6561	33	83	1000
[S II]	6730	52	86	1670
[O III]	5026	55	59	400
Continuum	6096	134	57	600

[a] Filter characteristics measured directly in f/7.5 beam.

Figure 1*b* are (6–10) × 10^{-16} ergs s^{-1} cm^{-2} $arcsec^{-2}$. Relative intensities in the two lines as measured from the images vary in the range 0.15 ≲ [S II]/Hα ≲ 3.0. In a short (400 s) exposure we did not detect [O III] emission; we obtain an upper limit of 0.8 × 10^{-16} ergs s^{-1} cm^{-2} $arcsec^{-2}$ for emission at 5007 Å from any features in the field comparable in size to those seen in [S II] and/or Hα.

2.2. *Spectroscopy*

A long-slit spectrum of G203.2 − 12.3 was obtained on 1991 January 17 with the du Pont telescope and modular spectrograph, using a 600 line mm^{-1} grating and 2″.25 slit. Integrations totaling 4000 s were taken at the orientation indicated in Figure 2. The data were reduced using standard IRAF procedures and were flux-calibrated based on observations of Stone & Baldwin (1983) standards. We have extracted spectra of three filaments at the positions indicated, to give the one-dimensional spectra shown in Figure 3. The line intensities are tabulated in Table 3; the dereddened values were calculated using Miller & Mathews's (1972) fits to the Whitford extinction curve, assuming an intrinsic Hα:Hβ ratio of 3. We obtain values 0.33 ≲ $E(B-V)$ ≲ 0.42 for the observed filaments. For comparison, the reddening to extragalactic sources in the direction of G203.2 − 12.3 is estimated by Burstein & Heiles (1982) as 0.56.

Spectroscopy confirms the generally high [S II]/Hα ratios, and the large variation in values, 0.25 ≲ [S II]/Hα ≲ 5.5. (The somewhat lower values from imaging are largely attributable to inflation of the "Hα" intensity by [N II] λλ6548, 6583 passed by the interference filter.) The [S II]/Hα ratio is generally taken as a diagnostic for whether material is shock-heated or photoionized, since shocks usually give rise to an extensive cooling zone in which radiation from low-ionization species is prominent. SNRs typically have values for [S II]/Hα ≳ 0.4, while H II regions and planetary nebulae usually have [S II]/Hα ∼ 0.1 (Dopita et al. 1984; Fesen, Blair, & Kirshner 1985). Most of the emission from G203.2 − 12.3 has [S II] ≳ Hα, and the most extreme filaments have remarkably high [S II]/Hα ratios, larger than any reported by Dopita et al. or Fesen et al. (1985) for evolved SNRs. This could indicate a high sulfur abundance due to the presence of supernova ejecta in a relatively young SNR. However, the abundances are different from, and far less extreme than, those in the ejecta-rich SNRs such as Cas A, all of which show very high oxygen abundances and virtually no hydrogen (e.g., van den Bergh 1988 and references therein). The electron densities in the filaments can be estimated from the [S II] λ6716/λ6731 ratio (Blair & Kirshner 1985) at 100–200 cm^{-3}, well above the low-density limit. These values further suggest a stellar or circumstellar origin for the emitting matter, since high-density regions of interstellar material should be rare at the probable distance of G203.2 − 12.3 from the Galactic plane.

TABLE 2

ASTROMETRY OF REFERENCE STARS

Star	R.A.(1950)	Decl.(1950)
A	5ʰ47ᵐ09ˢ.7	+2°54′43″
B	5 47 16.7	+2 51 57
C	5 47 21.1	+2 54 21
D	5 47 25.3	+2 52 49

TABLE 3

EMISSION-LINE INTENSITIES

LINE IDENTIFICATION	POSITION 1		POSITION 2		POSITION 3	
	$F(\lambda)$	$I(\lambda)$	$F(\lambda)$	$I(\lambda)$	$F(\lambda)$	$I(\lambda)$
Hβ λ4861	70	100	64	100	(70)	(100)
[N I] λ5199	...	...	17	24	...	...
[O I] λ6300	31	32	87	92	309	323
[O I] λ6364	10	10	30	32	117	125
[N II] λ6548	13	13	17	17	56	56
Hα λ6563	300	300	300	300	300	300
[N II] λ6583	36	36	51	51	180	180
[S II] λ6716	40	39	196	190	925	903
[S II] λ6731	35	34	154	149	720	702
Hα intensity[a]	6.3	12.8	1.4	3.4	0.19	0.38
$E(B-V)$ (mag)	0.33		0.42		0.34	

NOTE.—Parentheses denote values with large uncertainty.
[a] Units of 10^{-16} ergs s^{-1} cm^{-2} $arcsec^{-2}$.

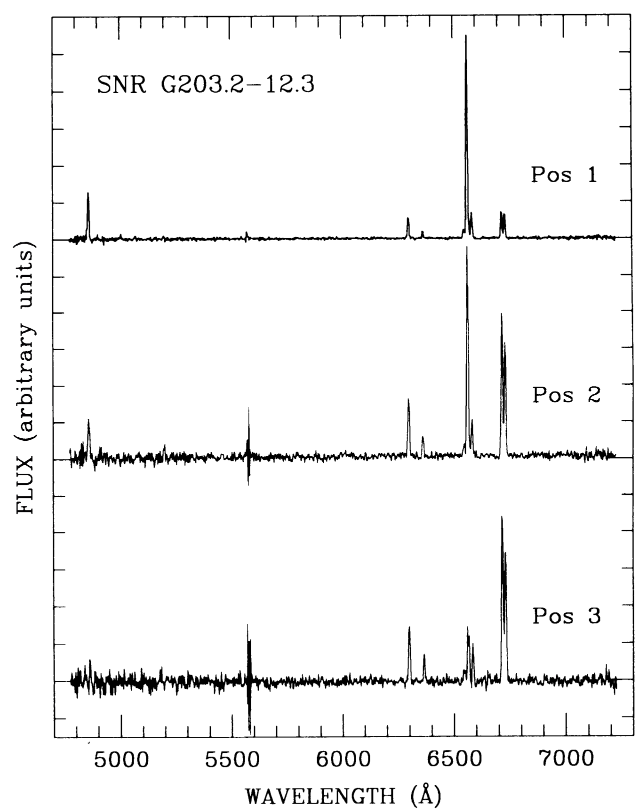

FIG. 3.—Spectra of the SNR G203.2 − 12.3, taken at positions indicated in Fig. 2. Note the great variation in relative strength of the [S II] and Hα lines. Relative to the position 1 spectrum, positions 2 and 3 are scaled by factors 5 and 10, respectively. (Line intensities are given in Table 3.)

All the filaments we have observed spectroscopically have low velocities, $|v| \lesssim 200$ km s^{-1}, and the lines have widths ≈ 8 Å, consistent with the instrumental resolution. Very small velocity variations occur along the slit, but we can place an upper limit of 200 km s^{-1} on velocity dispersion leading to broadening or to variations from filament to filament at our slit position. Were high velocities (characteristic of supernova ejecta, as seen in Cas A and similar remnants) observed in G203.2 − 12.3, this would provide strong evidence that the object is a young SNR. However, the absence of evidence for high velocities cannot be taken as an argument against the youth of the object. Several young SNRs have only low-velocity filaments, e.g., RCW 86 (SN 1985) and Kepler (SN 1604), and even in Cas A the numerous quasi-stationary flocculi have velocities of ~ 300 km s^{-1} or less. In all these cases, the filaments are believed to stem largely from shocked circumstellar material. These other young remnants differ from G203.2 − 12.3 spectroscopically, however, in that they all have high nitrogen abundance, typical of matter lost from a massive star, while G203.2 − 12.3 is sulfur-rich.

3. DISCUSSION

In the compilations of astronomical events recorded historically (Ho 1962; Clark & Stephenson 1977), one event near the position of G203.2 − 12.3 has been noted, recorded in A.D. 483 in the history of the northern Wei dynasty. According to Clark & Stephenson, this event was cataloged as a *k'o-hsing*, or guest star, the same category used for the well-known supernovae of A.D. 185, 1006, 1054, 1572, and 1604. However, nothing is known about the duration of the A.D. 483 event, making it difficult to identify it unambiguously as a supernova. The position is given by Ho as in Shen (the 21st lunar mansion), clearly identified in the northeastern quadrant of Orion, extending over about 10° from the "belt" to Betelgeuse. G203.2 − 12.3 lies near the center of this asterism, so the positional coincidence is excellent. In view of its location in one of the most easily recognizable regions of the sky, other contemporary observations may have been recorded, and it would be most interesting if additional recorded sightings of the A.D. 483 guest star could be found.

Whether or not G203.2 − 12.3 is the remnant of a historical supernova, its location alone, toward the Galactic anticenter and at a latitude that is unusually high for an SNR, makes it noteworthy. Of the 155 SNRs in the catalog of Green (1988), only 32 are located within 90° of the anticenter, $90° \leq l \leq 270°$, and only 12 are located in the quadrant extending $\pm 45°$ from the anticenter. Most of these have been detected optically as well as through their radio emission: 10 of 12 within $135° \leq l \leq 225°$, and 20 of 32 within $90° \leq l \leq 270°$. This compares with only 22 optical SNRs from among a total of 123 around the other half of the Galactic plane. The sample of Galactic SNRs may be most complete near the anticenter (van den Bergh 1991), so the addition of new remnants there is significant. More unusual is G203.2 − 12.3's Galactic latitude. Only four SNRs from the Green catalog are located at $b \geq 10°$, and only two, the SN 1006 remnant (G327.6 + 14.6) and the Lupus Loop (G330.0 + 15.0), are at higher latitude than G203.2 − 12.3.

We can say little about the distance to G203.2 − 12.3. The reddening to extragalactic sources in this direction is $E_\infty(B-V) = 0.56$ (Burstein & Heiles 1982), and the observed reddening to G203.2 − 12.3 of 60%–75% of this value can be used for an estimate. If we assume that material responsible for reddening is distributed above and below the Galactic plane with density proportional to $e^{-|Z|/H}$, where H is the scale height, then the distance is given by

$$d \approx \frac{H}{\sin 12\overset{\circ}{.}3} \ln\left[1 - \frac{E(B-V)}{E_\infty(B-V)}\right].$$

This suggests extremely close distances, $d \sim 90$–$140(H/100 \text{ pc})$ pc, for reasonable values of H. A small, local decrease in $E_\infty(B-V)$ could give a much larger distance, however. If the angular diameter of G203.2 − 12.3 is 3′, its linear diameter is $0.9(d/1 \text{ kpc})$ pc, so this is a small SNR even if it is as distant as 5 kpc, on the outer fringes of the Galaxy. The small size is paradoxical; the remnants of SN 1006 and SN 1572 (Tycho), both of which are presumably younger, are much larger in angular size, and probably in linear diameter as well. Yet it is unlikely that the small size of G203.2 − 12.3 results from the slowing of its expansion by a high-density region, located as it is well outside the Galactic plane. The true extent of the remnant, as measured by its radio and/or X-ray emission, might be large compared with that of the optical filaments, as in the morphologically similar RCW 89 (MSH 15 − *52*; Seward et al. 1983) and several other cases.

While we favor the identification of G203.2 − 12.3 as an SNR, based on its filamentary structure and its spectrum, other interpretations for this object cannot be excluded on the basis of the optical data. One alternative is a low-ionization planetary nebula such as Sharpless 216 (Fesen, Blair, & Gull 1981). In no known planetary nebulae, however, do we find [S II] emission as strong (relative to Hα) as that observed in G203.2 − 12.3. Kaler (1981) and Aller & Keyes (1987) give spectra for numerous planetaries, all less extreme than we have observed. Furthermore, we have searched for a central exciting star by comparing stellar fluxes on our [O III], [S II], and red continuum frames, and we find no unusually blue candidates.

Observations of G203.2 − 12.3 at other wavelengths, especially X-ray and radio, should help to clarify the nature of this object. If it is indeed an SNR, then we would expect to see the extended, nonthermal radio emission which characterizes virtually all remnants, and quite likely X-ray emission as well, especially if it is a young remnant. Based on typical values for the relation between X-ray absorption and optical reddening, e.g., $N_{\rm H} = (6.8 \pm 1.6) \times 10^{21} E(B-V)$ cm^{-2} (Ryter, Cesarsky, & Audouze 1975), we would expect modest X-ray absorption: $N_{\rm H} \approx (2$–$3) \times 10^{21}$ cm^{-2}. G203.2 − 12.3 should be a likely candidate for observation in soft X-rays from *ROSAT*. Radio and X-ray observations should cover a field significantly wider than 3′, since the optical filaments may not indicate the full extent of the remnant. Additional optical data will also be useful, especially more extensive spectroscopy to elucidate the wide variations in relative line strengths and to probe their causes. Finally, further investigation of the A.D. 483 event and its possible association with G203.2 − 12.3 would be of great interest.

We are grateful to H. E. Schuster and to G. and O. Pizarro, who took the ESO Schmidt plate on which G203.2 − 12.3 was first noted. We wish to thank the support staff at Las Campanas for their able assistance during the acquisition of the data presented here, Knox Long for sharing his observing time, and Robert Kirshner for loaning his interference filters. This research has made use of the SIMBAD data base, operated at CDS, Strasbourg, France. During this work, P. F. W. has been a Visiting Resident Scientist at the Cerro Tololo Inter-American Observatory and a Visiting Fellow at the Joint Institute for Laboratory Astrophysics, and he appreciates the hospitality of both these institutions. Financial support has been provided in part by the NSF through grants AST-8520557 and AST-9114935.

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