arXiv:astro-ph/9602126v1 23 Feb 1996

The Extraordinary Abundances of QSO Broad Absorption Line Regions: A Matter of Novae?

Gregory A. Shields
Department of Astronomy
The University of Texas at Austin
Austin, TX 78712

Subject headings: accretion, accretion disks — novae, cataclysmic variables — galaxies: abundances — quasars: absorption lines

ABSTRACT

The broad absorption lines (BALs) of QSOs indicate abundances of heavy elements, relative to hydrogen, that are 1 to 2 orders of magnitude higher than the solar values. In at least one QSO, an especially large enhancement of phosphorus is observed. These abundances resemble those in Galactic novae, and this suggests that novae may produce the BAL gas. The needed rate of nova outbursts may come from single white dwarfs that accrete gas as they pass through a supermassive accretion disk around a central black hole.

1. Introduction

BAL QSOs show broad absorption troughs attributed to rapidly outflowing gas, of unknown origin, located outside the continuum source and the broad emission-line region. BALs typically occur in Lα, C IV λ1549, Si IV λ1400, N V λ1240, O VI λ1034, and sometimes Mg II λ2798 and Al III λ1857 (see reviews by Weymann, Turnshek, and Christiansen 1985, "WTC"; and Turnshek 1988, 1995). BALs often set in at the systemic velocity of the QSO, but in some objects "detached" BALs begin at a velocities up to $\sim 10^4$ km s^{-1}. The absorption often extends to velocities $\sim 3 \times 10^4$ km s^{-1}, with varying degrees of structure and residual intensity through the line profile. The derived column densities for the absorbing ions (e.g., C^{+3}) are $\sim 10^{16}$ cm^{-2}. BALs occur in about 10 percent of radio quiet QSOs (Weymann et al. 1991) and rarely in radio loud QSOs . Either most radio quiet QSOs have BAL material covering about 10 percent of the sky as seen from the continuum source, or a subset of QSOs have BAL regions with a larger covering factor. The BAL region may have a disk-like geometry (Turnshek 1995; Goodrich and Miller 1995). The absorbing material must have a transverse dimension $\gtrsim 10^{16}$ cm, sufficient to cover the continuum source. The N V BAL often strongly absorbs the Lα emission line, implying a radius $\gtrsim 10^{18}$ cm (Turnshek et al. 1996). The absorbing clouds, which occupy only a tiny fraction of the volume, may be accelerated by radiation pressure involving the resonance lines or by ram pressure of a fast moving wind (WTC). Proposed sources for the BAL gas include winds from red giant stars (Scoville and Norman 1995) or from a supermassive accretion disk (Murray et al. 1995).

2. Chemical Abundances

The BAL gas has remarkably high abundances of heavy elements, relative to hydrogen. The abundances are derived from column densities of ions (in turn derived from observed BAL optical depths) together with photoionization models of the ionization equilibrium. Junkkarinen et al. (1987) argued for a minimum $(\mathrm{Si/H}) \geq 10(\mathrm{Si/H})_\odot$ for their sample of BAL QSOs, and their discussion suggests a likely value $(\mathrm{Si/H}) \approx 25(\mathrm{Si/H})_\odot$. Turnshek et al. (1987) reported a C/H ratio 10 to 100 times the solar value in Q0932+501 (see also WTC); and for Q1413+113, they found that S/C and either P/C or Fe/C are at least 100 times solar. For Q0226-1024, Korista et al. (1992, 1995) found a heavy element abundance $\mathrm{Z/Z}_\odot \approx 5$ to 10, in the context of an assumed chemical evolution scenario. Analyzing the same observations of Q0226-1024, Turnshek et al. (1996) developed atwo component photoionization model that gave ratios $\sim$ 4, 3, 9, and 120 times solar for N/O, N/Si, N/C, and N/H respectively (best fit model). Enhancements of other elements, including S and Ar, are observed in some cases (Turnshek 1995). Remarkably, P/C is $\sim$ 65 times the solar value in PG 0946+301 (Junkkarinen et al. 1995; Junkkarinen 1995). The heavy element enhancements can be reduced, but not eliminated, by using complicated shapes for the ionizing continuum (WTC).

Novae show very large enhancements of C, N, O and sometimes Ne, Mg, Al, Si, S, Ar, Ca, and Fe (Andreä et al. 1994, and references therein). Novae are produced by thermonuclear explosions on the surface of white dwarf stars accreting hydrogen rich gas from a close companion star (see review by Starrfield 1989). The ejected gas is enriched with heavy elements mixed in from the white dwarf. Enhancements of Ne and heavier elements, observed in "neon novae", are attributed to events on O-Ne-Mg white dwarfs (Politano et al. 1995, and references therein). Hydrogen burning leads to especially large enhancements of nitrogen, and in the case of O-Ne-Mg white dwarfs, heavier odd numbered elements. Fig. 1 illustrates the abundances in a set of novae, determined in a uniform manner by Andreä et al. (1994). Abundances of C, O, and Si are typically enhanced by one to two orders-of-magnitude, compared with solar values; and N/H is enhanced by two to three orders-of-magnitude.

I have estimated abundances for several BAL QSOs by assuming that their elemental abundance ratios scale from those given by Turnshek et al. (1996) for Q0226-1024 in proportion to the corresponding ionic column densities. (This assumes that the ionization corrections are similar in all these objects. Column density ratios for ions of a single element are generally unavailable to constrain models for individual objects.) Column densities were taken from Junkkarinen et al. (1987) for 5 BAL QSOs and from Junkkarinen (1995) and co-workers for Q0946+301. Figure 1 shows the resulting abundance ratios along with a value $(\mathrm{C/H}) = 30(\mathrm{C/H})_\odot$ for Q0932+501 (Turnshek et al. 1987). The abundance distributions for C, N, O, and Si for novae and BAL QSOs are similar. Politano et al. (1995) predict P/C ratios of $\sim$ 50 and 300 times solar for nova explosions on O-Ne-Mg white dwarfs with masses of 1.25 and 1.35 $\mathrm{M}_\odot$, respectively, bracketing the value for PG0946+301. These results suggest that the BAL gas may come from novae in a massive star cluster in the active galactic nucleus.

High Si/C and P/C in BAL QSOs suggests that neon novae are typically involved. If O-Ne-Mg white dwarfs come only from progenitors of mass 8—10 $M_\odot$ (Nomoto 1984), they should be only a few percent of Galactic white dwarfs. Truran and Livio (1986) attempted to explain the high observed incidence of neon novae in the Galaxy in terms of a small accreted mass per outburst. However, observed masses of neon nova shells are $\sim 10^{-4}$ $M_\odot$ (e.g., Shore et al. 1993), so another explanation may be needed. If O-Ne-Mg white dwarfs come from progenitors down to ~ 5 $M_\odot$ (Chiosi et al. 1989), these would be a large fraction of all white dwarfs for a cluster age $\sim 10^8$ yr, the likely duration of a QSO episode (Norman and Scoville 1988). Alternatively, perhaps nuclear burning to high atomic numbers, which Politano et al. (1995) find only for the most massive white dwarfs, actually occurs for lower masses as well. Finally, if the BAL geometry is such that debris of different novae are comingled, as might occur in the disk geometry of Section 4, neon novae could contribute heavier elements to the mix.

The heavy element abundances in the broad emission-line gas of QSOs may be up to an order of magnitude higher than solar, relative to hydrogen (Hamann and Ferland 1993), but apparently are not so high as in the BAL gas. The emission-line abundances have been attributed to rapid chemical evolution involving the usual stellar sources of heavy elements (Hamann and Ferland 1993), and this would not explain high P/C. This suggests that the two regions likely have different origins.

3. Ordinary Novae

Novae are minor sources of interstellar gas in the Galaxy. Can they nevertheless be the dominant source of BAL gas? We first consider ordinary novae in a massive nuclear star cluster and then the possibility of accretion onto single white dwarfs passing through a supermassive accretion disk.

The mass of a nova shell typically is $M_{ej} \approx 10^{-4.3}$ $M_\odot$ (Warner 1989). As the shell expands and accelerates radially outward, it presumably fragments into a collection of clouds or filaments. We assume that the lateral expansion continues at the original ejection velocity, $v_{nov} \approx 2000$ km s^{-1}, appropriate for neon novae (e.g., Ferland, Lambert, and Woodman 1977; Shore et al. 1993; Gehrz et al. 1985). The column density of carbon atoms through the debris is $N_C \approx M_C/(\pi r_{sh}^2 m_c)$, where r_{sh} is the shell radius, M_C is the mass of carbon in the nova shell, and m_C is the mass of a carbon atom. Therefore, we may write

$$r_{sh} \approx (10^{17.3}\ \mathrm{cm}) M_{C,-5}^{1/2} N_{C,16}^{-1/2}, \qquad (1)$$

where $M_{C,-5} \equiv M_C/10^{-5}$ $M_\odot$ and $N_{C,16} \equiv N_C/10^{16}$ cm^{-2}. For a carbon abundance $C/H = 10^{1.5}(C/H)_\odot$, we expect $M_C \approx 10^{-5.5}$ $M_\odot$. Assuming that roughly half of the carbon is C^{+3}, we find $N_{C,16} \approx 1$ for $r_{sh} \approx 10^{17.0}$cm. This radius is large enough to cover the continuum source and, within the uncertainties, the Lα emitting region. As the debris expand, the continuum radiation pressure presumably ablates off material in the form of small clouds, which move radially outward as they are accelerated to the observed outflow velocities (cf. WTC). For $\Delta R/r_{sh} \approx w/v_{nov}$, $N_{C,16}$ drops to unity for distances $\Delta R \approx (w/v_{nov})r_{sh} \approx 10^{18}$ cm from an initial location at radius R_{init}, where $w \approx 10,000$ km s^{-1} is the outflow velocity.

The expected covering factor for nova shells depends on the nova rate in the star cluster in the galactic nucleus. The covering factor for one shell is $\Omega_{sh}/4\pi \approx \pi r_{sh}^2/(4\pi R^2) \approx 0.25(v_{nov}/w)^2$, where the second equality assumes $R_{init} < \Delta R$. The number of shells in play at a given moment is $N_{sh} \approx \dot{N}R/w$, where $\dot{N}$ is the rate of nova explosions and $R/w \approx r_{sh}/v_{nov}$ is the crossing time. We evaluate $\Omega/4\pi$ for the value of r_{sh} that gives $N_{C,16} \approx 1$. This leads to

$$\Omega/4\pi \approx 0.25\dot{N}r_{sh}v_{nov}w^{-2} \approx 10^{0.15}\dot{N}_o(v_{nov}/w)w_9^{-1}M_{C,-5}^{1/2}N_{C,16}^{-1/2}, \tag{2}$$

where $\dot{N}_o$ is the nova rate per year and $w_9 \equiv w/(10^9 \text{ cm s}^{-1})$. If $R_{init} \gtrsim \Delta R$, this result should be adjusted accordingly. Note that $\Omega/4\pi$ varies as $(\dot{N}M_{ej})M_{ej}^{-1/2}$, so that events involving a small mass, such as novae, are highly effective for a given average mass-loss rate, $\dot{N}M_{ej}$. The nova rate in the Galaxy (mass $\sim 10^{11}$ M$_\odot$) is $\sim 40\ yr^{-1}$ (Warner 1989, Ciardullo et al. 1990); and therefore we take $\dot{N}_o \approx 10^{-1.4}M_{cl,8}$, where $M_{cl,8}$ is the mass of the nuclear star cluster in 10^8 M$_\odot$. Then we find

$$\Omega/4\pi \approx 10^{-1.1}M_8(v_{nov}/w)w_9^{-1} \approx 10^{-1.8}M_8. \tag{3}$$

A ten percent covering factor requires $M_8 \approx 10$. Analogous estimates of the covering factor for BAL absorption due to planetary nebulae, supernova remnants, and "stellar contrails" (Scoville and Norman 1995) indicate that novae are competitive or dominant by up to an order of magnitude. However, none of these sources match the BAL abundances as naturally as do novae.

The mass loss rate in carbon alone can be estimated as

$$\dot{M}_C \approx N_C m_C 4\pi R^2(R/w)^{-1}(\Omega/4\pi) \approx (10^{-4.4}M_\odot\ yr^{-1})N_{C,16}R_{18}w_9(\Omega/4\pi). \tag{4}$$

For $N_{C,16} \approx R_{18} \approx w_9 \approx 1$ and $\Omega/4\pi \approx 0.1$, this gives $\dot{M}_C \approx 10^{-5.4}$ M$_\odot$ yr^{-1}. For $C/H \approx 30(C/H)_\odot$, the total mass loss rate then is $\sim 10^{-4.2}$ M$_\odot$ yr^{-1}, a rather modest value.

Norman and Scoville (1988) discussed a coeval star cluster of mass $\sim 10^9$ M$_\odot$ whose evolutionary debris fuel the central black hole. The age of the nuclear star cluster is at most $10^{9.3}$ yr at redshift $z = 2$ for $q_o = 1/2$ and $H_o^{-1} = 15$ Gyr, and it could be as young as the estimated QSO lifetime of $\sim 10^8$ yr. The "evolutionary flux" of stars leaving the main sequence drops an order-of-magnitude as a coeval cluster evolves from age 10^8 to age $10^{9.5}$ years and somewhat further by age 10^{10} years (Norman and Scoville 1988). The effect of this on the nova rate is unclear. The required star cluster, confined to a radius not much larger than 10^{18} cm, would have a stellar velocity dispersion of several thousand km s^{-1}. The stellar collision time would be shorter than the Hubble time and possibly even the estimated $\sim 10^8$ yr lifetime of a QSO episode. Observations of nearby galactic nuclei offer little support for such massive nuclear star clusters (e.g. Lauer et al. 1992, and references therein). Thus, we are motivated to consider ways to enhance the nova rate in QSOs.

4. Single White Dwarfs

An intriguing possibility is suggested by the work of Artymowicz, Lin, and Wampler (1993, ALW). They consider stars on orbits passing through an accretion disk around a central black hole of mass M_h, accreting disk gas during each passage. White dwarfs orbiting through the disk will also accrete disk material, and this raises raises the possibility of nova explosions on single white dwarfs that have accreted the requisite amount of hydrogen rich gas (cf. Truran et al. 1977). The circular velocity in units 10^8 km s^{-1} is $v_{c,8} \approx 10^{0.1} M_{tot,8}^{1/2} R_{18}^{-1/2}$, where $M_{tot} = M_h + M_{cl}$. The average stellar velocity, v_*, will be roughly v_c. Let v_{rel} be the velocity of a star relative to the orbiting material in the disk. If the cluster is corotating with the disk, most stars will have v_{rel} substantially less than v_*. For parameters of interest, v_{rel} is less than the escape velocity from the surface of a white dwarf and large compared with the sound speed in the disk. The accretion rate onto the white dwarf while in the disk is

$$\dot{m} \approx 2.5\pi G^2 m^2 \rho v_{rel}^{-3} \tag{5}$$

(Bondi and Hoyle 1944), where $m \approx 1\ M_\odot$ is the mass of the white dwarf and ρ is the gas density in the disk. Following ALW, we assume that the disk thickness H is such that the Toomre (1964) stability parameter, Q, is near unity. Consequently, $\pi \Sigma R^2/M_H \approx H/R \approx 10^{-2}$, where $\Sigma = 2H\rho$ is the disk surface mass density and a value $H/R \approx 10^{-2}$ corresponds to the disk's expected vertical equilibrium. Then $\Sigma \approx (10^{2.8}\ \mathrm{g\ cm^{-2}})\mathrm{M_{h,18}R_{18}^{-2}}$, $\rho \approx (10^{-13.5}\ \mathrm{g\ cm^{-3}}) M_{h,8} R_{18}^{-3}$, and $\dot{m}_o \approx 10^{-10.1} M_{h,8} R_{18}^{-3} v_{rel,8}^{-3}$, where $\dot{m}_o \equiv \dot{m}/1\ \mathrm{M_\odot\ yr^{-1}}$. If the star's vertical velocity v_z is $\sim v_{rel}/\sqrt{3}$, then the duration of passage through the disk is $\Delta t \approx (10^{0.7}\ \mathrm{yr}) R_{18} v_{rel,8}^{-1}$, and the mass accreted is $\Delta m \approx (10^{-9.4}\ \mathrm{M_\odot}) M_{h,8} R_{18}^{-2} v_{rel,8}^{-4}$. If this much mass is accreted twice per orbital period, $P \approx 2\pi R/v_* = (10^{3.3}\ \mathrm{yr}) R_{18} v_{*,8}^{-1}$, then the average accretion rate is $\langle \dot{m}_o \rangle \approx (10^{-12.4}) M_{h,8} R_{18}^{-3} v_{*,8} v_{rel,8}^{-4}$. A typical white dwarf will undergo an explosion at intervals $t_{nov} \approx (10^{8.1}\ \mathrm{yr}) M_{h,8}^{-1} R_{18}^{3} v_{*,8}^{-1} v_{rel,8}^{4}$.

Suppose there are $N_{WD} \approx 10^7 M_{cl,8}$ white dwarfs in the nuclear star cluster (Allen 1973). (For a Salpeter [1955] initial mass function ranging from 0.2 to 20 $\mathrm{M_\odot}$ and a main sequence turnoff of 1.4 $\mathrm{M_\odot}$, corresponding to an age of $10^{9.3}$ yr, one has $N_{WD} \approx 10^{6.8} M_{cl,8}$.) Let the stars have a typical velocity $\sigma \le v_*$ in the frame corotating with the disk. Then the nova rate for most white dwarfs, with $v_{rel} \approx \sigma$, will be $\dot{N}_o \approx 10^{-1.1} M_{h,8} M_{cl,8} R_{18}^{-3} v_{*,8} \sigma_8^{-4}$. With $M_h \approx M_{cl}$ and $v_*^2 \approx G M_{tot}/R$, this gives $\dot{N}_o \approx 10^{-1.9} M_{tot,8}^{1/2} R_{18}^{-3/2} (v_*/\sigma)^4$. For $R_{18} \approx M_8 \approx 1$ and $\sigma/v_* \approx 0.5$, we then have

$$\Omega/4\pi \approx 10^{-0.8} (v_{nov}/w) w_9^{-1} \approx 10^{-1.5}. \tag{6}$$

However, accretion is most rapid onto stars with small v_{rel}, and these can dominate the nova rate in spite of their relatively small numbers, $N(v_{rel})/N \approx (v_{rel}/\sigma)^3$. If relative velocities down to some minimum, v_{min}, contribute to the nova rate, then a simple integration over v_{rel} shows that the preceeding expressions for $\dot{N}_o$ and $\Omega/4\pi$ should be increased by a factor $\sim (\sigma/v_{min})$. If violent nova explosions occur for $\dot{m} < 10^{-7}\ \mathrm{M_\odot\ yr^{-1}}$ (van den Heuvel et al. 1992), then we may take $v_{min} \approx 10^{6.6}\ \mathrm{cm\ s^{-1}} \approx 10^{-1}\sigma$. This increases $\dot{N}_o$ and $\Omega/4\pi$ by an order of magnitude, so that $\Omega/4\pi \approx 10^{-0.5}$. Within the uncertainties, this is consistent with the observed 10 percent incidence of BALs. For the assumed parameters, novae involving single white dwarfs outnumber ordinary novae by a factor ~ 40.

Indications of a flattened BAL region are consistent with novae from white dwarfs with small v_{rel}/v_*, which would orbit close to the disk ($z/R \approx v_{rel}/v_c$). The actual nova event would occur at a random place in the white dwarf's orbit. The association of BALs with radio quiet QSOs might involve the absence of a suitable accretion disk in radio loud objects, perhaps because the latter typically occur in elliptical galaxies.

5. Discussion

In summary, the high chemical abundances derived for the BAL region of QSOs resemble the abundances of Galactic novae. The mass of heavy elements in a nova shell is consistent with constraints on the dimensions and location of the BAL absorbing material. A very massive nuclear star cluster must be postulated in order for ordinary nova outbursts to explain the observed incidence of BALs in QSO spectra. Accretion of gas by white dwarfs passing through a supermassive accretion disk can provide sufficient nova outbursts with a more modest star cluster.

Observational consequences include a small BAL region that could show changes over a few years. Different velocity components in the BALs of a given object could result from different novae and show different abundances. Odd numbered elements such as Al and P should be especially enhanced in abundance.

This work was inspired in part by the talks by P. Artymowicz and V. Junkkarinen (who mentioned high P in nova models) at the June, 1995, meeting of the American Astronomical Society. I am grateful to F. Bash, R. Ciardullo, D. Lin, K. Korista, D. Lambert, S. Starrfield, D. Turnshek, and J. C. Wheeler for valuable discussions, and to V. J. and D. T. for communicating results in advance of publication. This work was supported in part by STScI grant GO-5434.03-93A.

REFERENCES

Allen, C. W. 1973, Astrophysical Quantities, (London: Athlone Press), 251

Andreä, J., Drechsel, H., & Starrfield, S. 1994, A&A, 291, 869

Artymowicz, P., Lin, D. N. C., & Wampler, E. J. 1993, ApJ, 409, 592

Bondi, H., & Hoyle, F. 1944, MNRAS, 104, 273

Ciardullo, R., Ford, H. C., Williams, R. E., Tamblyn, P., & Jacoby, G. H. 1990, AJ, 99, 1079

Chiosi, C., Bertelli, G., Meylan, C., & Ortolani, S. 1989, A&A, 219, 167.

Ferland, G. A., Lambert, D. L., & Woodman, J. H. 1977, ApJ, 213, 132

Gehrz, R. D., Grasdalen, G. L., & Hackwell, J. A. 1985, ApJ, 298, L47

Goodrich, R. W., & Miller, J. S. 1995, ApJ, 219, 167

Hamann, F., & Ferland, G. 1993, ApJ, 418, 11

Junkkarinen, V. T., 1995, personal communication

Junkkarinen, V. T., Beaver, E. A., Burbidge, E. M., Cohen, R. W., Hamann, F., Lyons, R. W., & Barlow, T. A. 1995, BAAS, 27, 872

Junkkarinen, V. T., Burbidge, E. M., & Smith, H. E. 1987, ApJ, 317, 460

Korista, K., et al. 1992, ApJ, 401, 529

Korista, K., Hamann, F., Ferguson, J., & Ferland, G. 1995, ApJ, in press

Lauer, T. R., et al. 1992, AJ, 103, 703

Murray, N., Chiang, J., Grossman, S. A., & Voit, G. M. 1995, ApJ, 451, 498

Nomoto, K. 1984, ApJ, 277, 291.

Norman, C., & Scoville, N. 1988, ApJ, 332, 124

Politano, M., Starrfield, S., Truran, J. W., Weiss, A., & Sparks, W. M. 1995, ApJ, 448, 807

Salpeter, E. E. 1955, ApJ, 121, 161

Scoville, N., & Norman, C. 1995, ApJ, 451, 510

Shore, S. N., Sonneborn, G., Starrfield, S., Rosario, G.-R., and Ake, T. B. 1993, AJ, 106, 2408.

Starrfield, S. 1989, in Classical Novae, ed. M. F. Bode, A.Evans (New York: Wiley), 39

Toomre, A. 1964, ApJ, 139, 1217

Truran, J. W., & Livio, M. 1986, ApJ, 308, 721

Truran, J. W., Starrfield, S. G., Strittmatter, P. A., Wyatt, S. P., & Sparks, W. M. 1977, ApJ, 211, 539

Turnshek, D. 1988, in QSO Absorption Lines: Probing the Universe, ed. J. C. Blades, D. A. Turnshek, C. Norman (Cambridge University Press), 17

Turnshek, D. 1995, in QSO Absorption Lines (An ESO Workshop held November 21–24, 1994, Garching bei München, Germany), ed. G. Meylan (Merlin - New York: Springer-Verlag), 223

Turnshek, D., et al. 1987, poster paper in QSO Absorption Lines: Probing the Universe, ed. J. C. Blades, C. Norman, D. A. Turnshek (Baltimore: STScI), 8

Turnshek, D. A., Kopko, M., Jr., Monier, E., Noll, D., Espey, B. R., & Weymann, R. J. 1996, ApJ, in press.

van den Heuvel, E. P. J., Bhattacharya, D., Nomoto, K., & Rappaport, S. A. 1992, A&A, 262, 97

Warner, B. 1989, in Classical Novae, ed. M. F. Bode, A. Evans (New York: Wiley), 1

Weymann, R. J., Turnshek, D. A., & Christiansen, W. A. 1985, in Astrophysics of Active Galaxies and Quasi-Stellar Objects, ed. J. Miller (Mill Valley: University Science Books), 333 (WTC)

Weymann, R. J., Morris, S. L., Foltz, C. B., & Hewett, P. C. 1991, ApJ, 373, 23

This preprint was prepared with the AAS LaTeX macros v4.0.

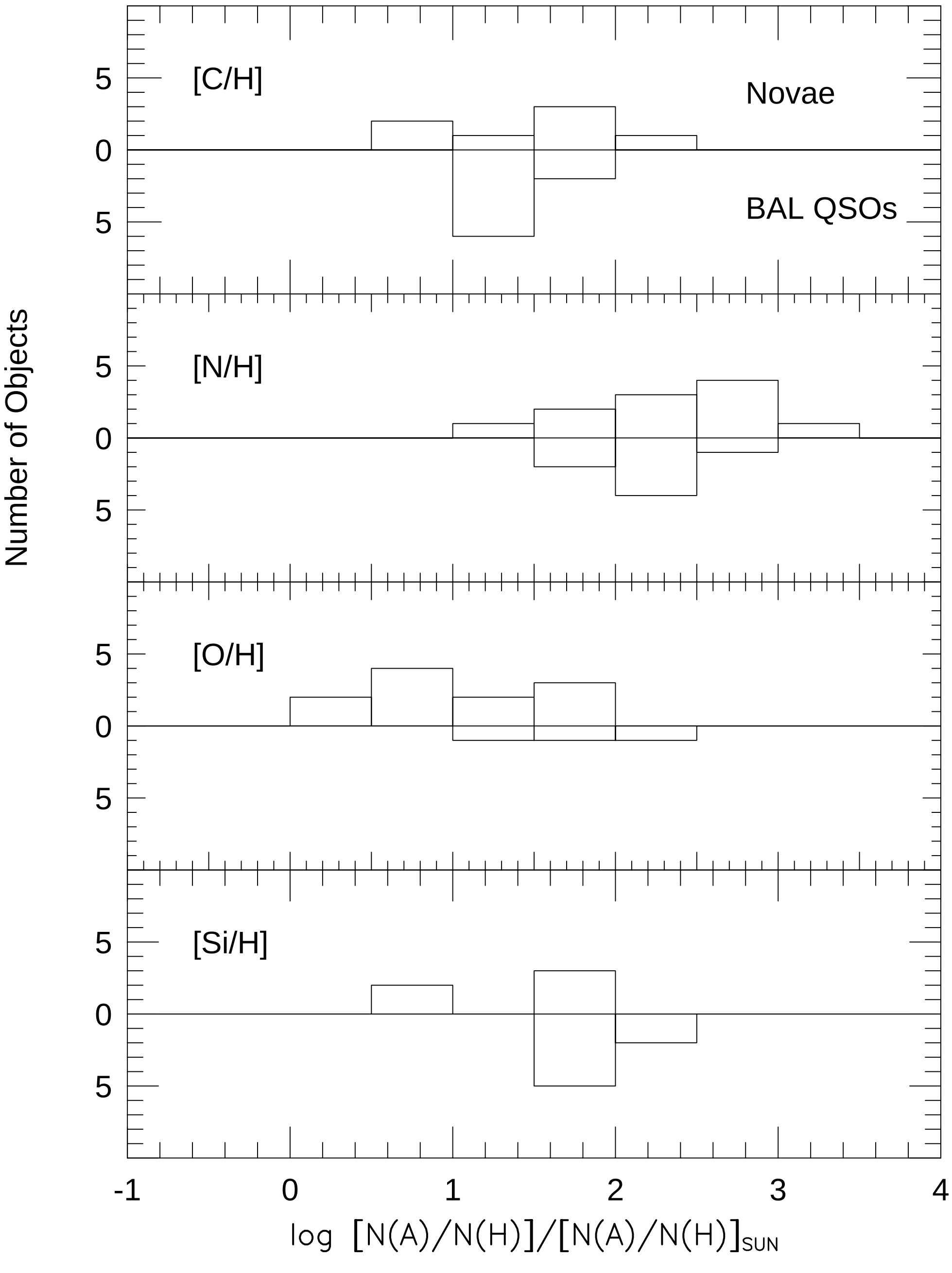

Fig. 1.— Histogram of C, N, O, and Si abundances relative to H for novae and BAL QSOs, in bins of 0.5 dex, normalized to solar ratios. In each panel, novae are shown above the horizontal axis and BAL QSOs below it. Each small tick on the vertical axis represents one object. Results for novae are from Andreä et al. (1994), and those for BAL QSOs are from several sources described in the text.