LETTER TO THE EDITOR

Based on a presentation made at the 90th Annual Meeting of the AAVSO, November 2, 2001

"The Corona of CN Leonis (Gliese 406) and Its Possible Detection at Radio Frequencies"

Gliese 406 = Wolf 359 is a nearby red dwarf (M6Ve spectral type) star 490,000 a.u. (2.4 pc) from the solar system with magnitude $V = 13.45$ and color index (B-V) = 2.00. It is in Leo, with equatorial coordinates (2000) $\alpha = 10^h\,56^m\,31^s$, $\delta = +07°00'$, and galactic coordinates $\ell = 244°.054$, b = +56°.118.

H. U. Sendig (1951, *Astron. Nach.*, **280**, 39) reported flare activity for Gliese 406, which led to its variable star name of CN Leonis. J. H. M. M. Schmitt and R. Wichmann (2001, *Nature*, **412**, 508) reported the detection of the Fe XIII emission line at λ = 3388.1 Å in the spectrum of CN Leo from a 3120-second exposure on the ultraviolet echelle spectrograph on the European Southern Observatory's Kueyen telescope. This is the first detection of coronal emission by ground-based observation in the optical window for a star other than the Sun.

If one considers the photosphere of CN Leo to be a black body at temperature $T = 2750$ K with the luminosity $L_{CN} = 0.0009\, L_{\odot}$, where $L_{\odot} = 3.825 \times 10^{26}$ W is the Sun's luminosity, and assumes a radius of 90,000 km for the photosphere of CN Leo, then $L_{CN} = 3.5 \times 10^{23}$ W, and one may use the Wien approximation to the Planck radiation function $B_{\lambda}(T)$, which is

$$B_{\lambda}(T) = \frac{2hc^2}{\lambda^5}\, e^{-\frac{hc}{\lambda kT}}, \tag{1}$$

where h is Planck's constant, c is the vacuum velocity of light, λ is the wavelength of the light, and k is the Boltzmann constant. For $\lambda = 3388$ Å, one finds $B(2750) = 0.52$ W/m^2 Å. The Fe XIII line observed by Schmitt and Wichmann in the corona of CN Leo shows turbulent broadening corresponding to the turbulence velocity $v_{turb} = 18.4$ km/s, and is also consistent with the coronal temperatures T_{co}: $1.6 \times 10^6\,\mathrm{K} < T_{co} < 2.75 \times 10^6$ K, and to volume emission measures N_e^2V: $7.8 \times 10^{48} \leq N_e^2V \leq 1.9 \times 10^{50}$ cm^{-3}, where Ne is the electron density, and V is the volume of the corona. These results from Schmitt and Wichmann indicate that the corona of CN Leo is similar to the Sun's corona.

If one takes $N_e \approx 10^8$ cm^{-3} as an overall average electron density in the corona of CN Leo, and the value $N_e^2V \approx 4 \times 10^{49}$ cm^{-3} as an average value for its volume emission measure, then, assuming a roughly spherical corona, one finds the outer radius R_{co} for the corona of CN Leo to be $\approx 10^{11}$ cm $\approx 10^6$ km. If one scales the corona of CN Leo to that of the Sun, which at the radio wavelength = 1 meter has a radius three times that of the Sun's photospheric radius, R'_{co} for the corona of CN Leo $\approx$ 300,000 km.

Let us now compare CN Leo to the closer (268,000 a.u.) flare star V645 Centauri = Proxima Centauri = Gliese 551 (spectral type dM5e). R. F. Malina *et al.* (1994, *Astron. J.*, **107**, 751) list both CN Leo and V645 Cen as x-ray sources; their coronae are probably the sources of their x-ray radiation. These two red dwarf variable stars are different in at least two ways:

1) No one has detected the corona of V645 Cen in the optical window, and
2) The corona of V645 Cen may have been detected at radio wavelengths, while that of CN Leo seems not yet to have been detected at radio wavelengths.

What radio telescope sensitivity might be needed to detect the corona of CN Leo at radio wavelengths? If the corona of CN Leo is similar to the Sun's at meter wavelengths, it would look like a black body at $T \approx 1{,}000{,}000$ K with a disk several times the photospheric radius of CN Leo. Here one may use the Rayleigh-Jeans approximation to the Planck radiation function, which is, in frequency ν, since $(h\nu / kT) << 1$,

$$B_\nu (T) = 2\nu^2 \, kT / c^2 . \qquad (2)$$

The flux F_{co} emitted by the corona in a bandwidth for a coronal radius R_{co} is

$$F_{co} = B_\nu (T) \, (\Delta\nu) \, (4\pi R_{co}^2) . \qquad (3)$$

If $\Delta\nu = 10^7$ Hz, at $\lambda = 1$ m $\nu = 3 \times 10^8$ Hz, and the coronal radius $R_{co} = 5 \times 10^5$ km, then $F_{co} = 8.67 \times 10^9$ W .

CN Leo is 7.33×10^{16} m from the solar system . If its corona radiates isotropically, then its brightness b_{co} will be 1.28×10^{-25} W/m^2 .

Radio astronomers measure their source brightnesses in *Janskys*, where a Jansky (Jy) is defined as 10^{-26} W/m^2 Hz. Since $\Delta\nu = 10^7$ Hz here, the radio brightness predicted here for the quiet corona of CN Leo is $b_{co} = 1.28 \times 10^{-6}$ Jy, or 1.28 μ Jy.

This is an extremely faint source, the detection of which will require use of the largest radio telescopes now available, such as the Very Large Array, preferably at its maximum extent and with a very wide bandwidth.

CN Leo should also be observed using smaller radio telescopes, since this analysis has been done for conditions assumed for its quiet corona. It may emit radio bursts similar to those that the Sun emits sporadically that are more powerful than its quiet corona, and which may sometimes be somewhat directed towards the solar system. This may have been the case for radio bursts that may have been detected from V645 Cen. Perhaps *serendipity* will help us in our effort to detect CN Leo *at radio wavelengths*!

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