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Possibility of measuring the amount of intergalactic metals with ^{14}N VII HFS line

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Abstract. We discuss possibility of observations of the warm-hot intergalactic medium using the hyperfine structure line of highly charged nitrogen ion ^{14}N VII (rest wavelength $\lambda = 5.652$ mm). Observations of this line will allow to separate bulk and turbulent motions in the observed target and will broaden the information about the gas ionization state, chemical and isotopic composition.

Wavelength of this line is well-suited for ground-based observation of objects at $z \approx 0.15 - 0.6$ when it is redshifted to the widely-used $6.5 - 9$ mm spectral band, and, for example, for $z \geqslant 1.3$, when the line can be observed in 1.3 cm band and at lower frequencies.

Keywords. galaxies: intergalactic medium - radio lines: general

1. Introduction

Hyperfine structure (HFS) lines of highly-charged ions may open a new window in observations of hot astrophysical plasmas. Radio observations of these lines will allow obtaining information about velocity field, mass, temperature and chemical abundance distribution of hot, warm and highly photoionized gas. The first discussion of the astrophysical applications of HFS lines was given by Sunyaev & Churazov (1984), who especially pointed out the millimeter lines of ^{14}N VII and ^{57}Fe XXIV.

The latter line was predicted to be bright in hot intracluster gas in clusters of galaxies at temperatures around 2×10^7 K. This line should also be bright in spectra of young supernova remnants, such as Cas A, if ^{57}Fe isotopic fraction in ejecta is not much less than the terrestrial value.

The ^{14}N VII line was not considered interesting for galactic astronomy, as its rest frequency of 53.041(15) GHz (Shabaev, Shabaeva & Tupitsyn (1995), Volotka *et al.* 2008) is in the wing of atmospheric oxygen absorption band. Sunyaev & Churazov (1984) proposed to use it for observations of objects having small positive redshifts, when the observed frequency moves out of this strongly attenuated spectral band. Following this idea, both theoretical studies (Sunyaev & Docenko (2007)) and observational searches (Bregman & Irwin (2007)) have been performed recently, aiming at the line detection from objects at redshifts $z > 0.15$. The ^{14}N VII HFS line is unique in the sense that it allows to study from the ground astrophysical plasma at temperatures around 10^6 K, that otherwise can be explored only by rocked-based and space ultraviolet and soft X-ray missions.

Several theoretical studies have focused on specific environments in which the ^{14}N VII HFS line might be detectable: surroundings of quasars (Docenko & Sunyaev (2007b)), hot interstellar medium in elliptical galaxies (Docenko & Sunyaev (2007a)).

In this contribution, we concentrate on a possible application of the ^{14}N VII hyperfine structure line for studies of intergalactic metals in the warm-hot intergalactic medium (WHIM).

According to modern hydrodynamical simulations of the large-scale structure of the Universe (e.g., Cen & Ostriker (1999)), the warm-hot intergalactic medium (rarefied intergalactic gas heated to temperatures $T \approx 10^5 - 10^7$ K) contains dominant fraction of barions in the present Universe. However, it is almost unobserved till now.

It is clear that radio observations of HFS lines of ions abundant in these conditions will provide additional information about the velocity field, mass, temperature and chemical abundance distribution of the warm-hot intergalactic medium. Interestingly, computations by Hellsten, Gnedin & Miralda-Escudé (1998), Cen & Ostriker (1999) show that heavy element abundances in the WHIM rise sharply in regions of higher temperature and density reaching values close to the solar ones.

2. The ^{14}N VII HFS line from the WHIM

While the solar abundance of ^{14}N relative to hydrogen is only 8×10^{-5}, the spontaneous decay rate of its hyperfine transition is 7×10^4 times higher. However, the WHIM column density is much lower than e.g. of the atomic gas in galaxies, and resulting typical optical depth of the ^{14}N VII HFS line is very small.

Let us compare it with the soft X-ray lines of O VII and O VIII, that are widely discussed as promising probes of the WHIM. Absorption cross-sections of these X-ray transitions around 20 Å are about three orders of magnitude larger than that of the HFS transition. Optical depth τ of the HFS transition is additionally diminished due to population of upper hyperfine sublevel in the field of the CMB radiation (see Sunyaev & Docenko (2007)). Resulting rough estimate of ^{14}N VII HFS line optical depth corresponding to O VII or O VIII soft X-ray line $\tau(\mathrm{O}) \approx 1$ is only about $\tau(^{14}\mathrm{NVII}) \approx (3-10) \cdot 10^{-5}$.

To assess frequency of occurrence of ^{14}N VII absorption lines in WHIM, we have used the distribution function of O VIII X-ray absorption line equivalent width from Cen & Fang (2006) and correspondence between the equivalent width and ionic column density from Chen *et al.* (2003) cosmological simulations. As a first approximation, we also assumed that in WHIM conditions the ionization equilibrium curve of O VIII atoms is the same as of N VII atoms and their relative abundance N/O is solar. Then on average in one sight line in the redshift intervals $z = 0.15 - 0.30$ and $z = 0.3 - 0.6$ we expect one ^{14}N VII HFS line with $\tau \geqslant 2 \cdot 10^{-5}$ and $\tau \geqslant 3 \cdot 10^{-5}$, respectively.

Our estimates of the ^{14}N VII occurrence frequency are plotted on Figure 1 with dashed lines, where they are compared with sensitivity of *Green Bank Telescope* (*GBT*) and planned performance of the *Square Kilometer Array* (*SKA*). The solid lines denote theoretical 3-σ detection limits of an absorption line in one velocity channel for several brightest quasars in mm and cm bands.

The decrease with redshift of the expected ^{14}N VII absorber number having the same optical depth is explained by combination of two effects: (a) increase of the CMB temperature and resulting line damping due to population of the upper HFS sublevel (Sunyaev & Docenko (2007)), and (b) decrease of the WHIM mass at redshifts higher than about one (Cen & Ostriker (1999)).

Although lines with optical depth of the order of 10^{-5} may seem too weak to be observable, emission lines of comparable line-to-background ratio have already been detected on the *GBT* by Vanden Bout, Solomon & Maddalena (2004).

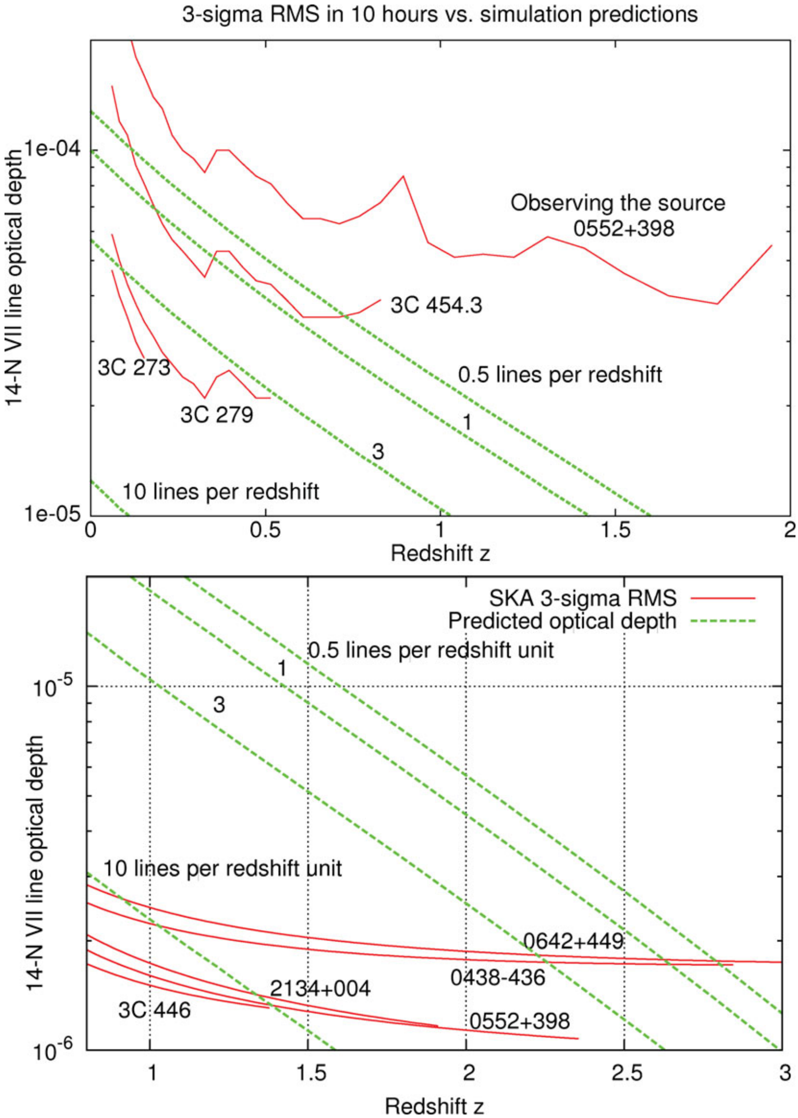

Figure 1. Expected ^{14}N VII line detection frequency on the sightlines to the brightest quasars. Green lines denote expected HFS absorption line depth frequency inferred from cosmological simulations. Red lines show 3-σ spectral line detection limits. (*Upper panel*) Observations with *GBT*, ten hours of on-source integration, 10 km/s spectral channel width; (*Lower panel*) Observations with *SKA*, one hours of on-source integration, 30 km/s spectral channel width. In one hour of integration, *SKA* will be able to detect five to ten lines at 3-σ level and about three lines at 10-σ level in redshift range from one to two.

3. Conclusions

Thanks to relatively high abundance of ^{14}N in the WHIM, the line of ^{14}N VII is the most prospective to be observed in absorption in spectra of brightest mm-band extragalactic radio sources with $z > 0.15$. Typical optical depth predicted for WHIM filaments reaches levels of several$\times 10^{-5}$ that is within the reach of the existing and planned instruments.

Using *GBT*, a 3-σ low-z WHIM detection would take about 10 hours on-source. With *SKA*, high-z detection may be achieved in less than an hour.

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References

Bregman, J. N. & Irwin, J. A. 2007, *ApJ* 666, 139

Cen, R. & Fang, T. 2006 *ApJ* 650, 573

Cen, R. & Ostriker, J. P., 1999 *ApJ* 514, 1

Cen, R. & Ostriker, J. P., 2006 *ApJ* 650, 560

Chen, X., Weinberg, D. H., Katz, N. & Davé, R. 2003 *ApJ* 594, 42

Docenko, D. & Sunyaev, R. A. 2007a, in: H. Böhringer, G. W. Pratt, A. Finoguenov, & P. Schuecker (eds.), *Heating versus Cooling in Galaxies and Clusters of Galaxies*, ESO Astrophysics Symposia (Berlin, Heidelberg: Springer), p. 333

Docenko, D. & Sunyaev, R. A. 2007b, in: *From Planets to Dark Energy: the Modern Radio Universe*, Published online at SISSA, *Proceedings of Science*, p.90

Hellsten, U., Gnedin, N. Y., & Miralda-Escudé, J. 1998 *ApJ* 509, 56

Shabaev, V. M., Shabaeva, M. B., & Tupitsyn, I. I. 1995, *Phys. Rev. A* 52, 3686

Sunyaev, R. A. & Churazov, E. M. 1984, *Soviet Astron. Lett.* 10, 201

Sunyaev, R. A. & Docenko, D. O. 2007, *Astron. Lett.* 33, 67

Vanden Bout, P. A., Solomon, P. M., & Maddalena, R. J. 2004 *ApJ* 614, L97

Volotka, A. V., Glazov, D. A., Tupitsyn, I. I., Oreshkina, N. S., Plunien, G., & Shabaev, V. M. 2008 *Phys. Rev. A* 78, 062507