Enhancement of the Forbidden Line in the Southwestern Knot of the Cygnus Loop

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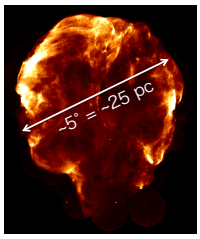
Abstract We observed the southwestern knot (SW-K) of the Cygnus Loop supernova remnant with XMM-Newton RGS. The high energy resolution of RGS enables us to resolve details of the line complex of SW-K below ~1 keV. We particularly focus on the OVII triplet in which the forbidden line is significantly enhanced relative to the resonance line. The measured forbidden-to-resonance line ratio is 1.75±0.13 which can not be explained by standard thermal plasma models such as collisional ionization equilibrium or ionizing plasmas.

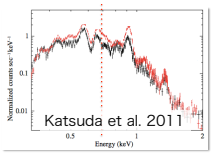
Recently, our comprehensive study of the Cygnus Loop with Suzaku XIS has found a possible sign of charge exchange (CX) from some points of its rim. Since the SW-K is one of these regions, the RGS spectrum provides a conclusive information about the presence of the CX emission. We will also discuss other important possibilities such as the recombination or the resonance scattering for the SW-K spectrum. The RGS observation will cast a new light on the X-ray studies of shock-cloud interactions in SNRs ahead of the ASTRO-H era.

Sign of CX from the Cygnus Loop

the Cygnus Loop



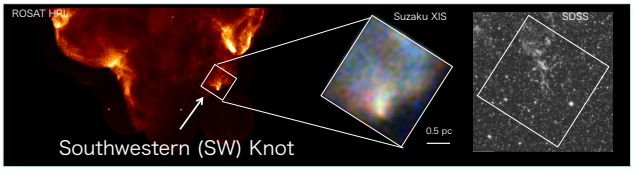
excess at ~0.7 keV

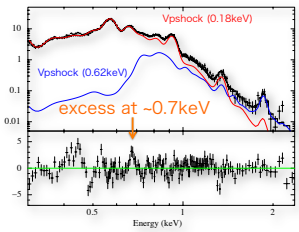


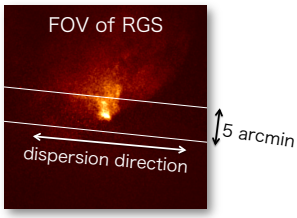
Possible Origin: Cascade line complex of K($\gamma+\delta+\varepsilon$ +...) from O^{+6} at ~0.7keV

Recently, we found a possible sign of charge exchange (CX) from some points of its rim; their spectra always show a strong excess at $\sim0.7 keV whose origin is likely a complex of cascade lines of He-like Oxygen. We have observed one of such regions, southwestern (SW) knot with XMM-Newton RGS.

Observation of the SW Knot with RGS

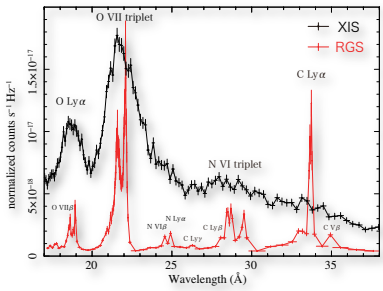






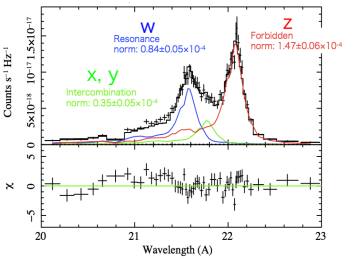
~100 ks observation

RGS Spectrum of the SW Knot



While Broad-band CCD spectrum suggests an ordinary thermal plasma of ~0.18 keV, the fine structure strongly indicates that the simple model does not explain the data.

OVII Triplet



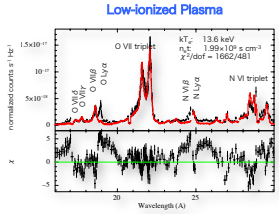
$R(n_e) = z/(x+y) \sim 2.4$
$G(T_e) = (z+x+y)/w \sim 2.2$

$F/R = z/w \sim 1.8$

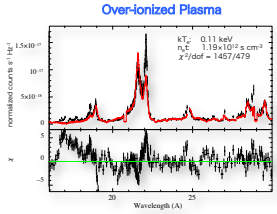
Surprisingly strong forbidden line !!

Spectral Fits with Several Models

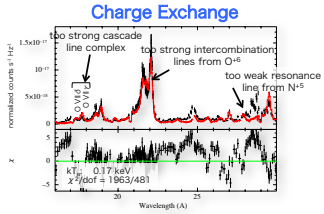
Low-ionized Plasma



Over-ionized Plasma

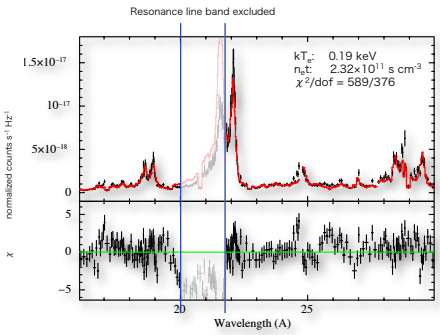


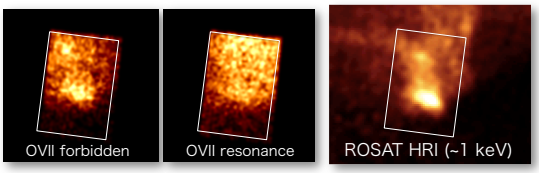
Charge Exchange



There are several origins which enhance the forbidden line. However, the low-/over- ionized plasma models give no reasonable fitting results. Furthermore, we found that the CX model (vacx; Smith et al. 2012) gives no acceptable fit.

Remaining Possibility: Resonance Line Scattering





A simple thermal model well explained the data when we excluded the energy band of the OVII resonance line. We also confirmed that the intensity map of the forbidden line clearly correlates with the broad band image, whereas the resonance line image shows a smoother feature. The simplest understanding is that the resonance line was scattered at regions where the column density is high.

$$p = \frac{1}{1+0.43\tau}$$ escape probability

$$\tau = \alpha n_Z L = \alpha \frac{n_Z}{n_Z}\frac{n_Z}{n_H}\frac{n_H}{n_e} n_e L$$ optical depth

$$= \alpha \times (Ion\ fraction) \times (Abundance) \times \frac{1}{1.2} \times \sqrt{EML}$$

While an escape probability calculated from another rim of the Cygnus Loop is ~0.7 for O VII Kα (Miyata et al. 2008), our result suggest ~0.5, which means τ should be ~2. Is it reasonable?

References
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