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The 6.7 keV Line Emission from the Stellar Flare of Algol

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Abstract

We present spectral analysis of Algol stellar flare data. The 2-day observation of Algol in our Galaxy was done by Suzaku Satellite. Algol binary system consists of two component stars that eclipse one another periodically. The stellar magnetic field activities and Roche Lobe overflow/mass transfer mechanisms during rapid rotation of the component stars generate an X-ray emission. The variation in brightness of the stellar flare from epoch to epoch provides useful information of stellar properties of the component stars. The atomic physics of the Kα line emission process in the vicinities of chromospherically active and X-ray flare stars, and binaries is well understood. The photo ionization/collisional excitation in the Algol's corona produces 6.7 keV line emission. The accumulated spectra in X-ray Imaging Spectrometer (XIS) sensors fitted combined with bremsstrahlung model and Gaussian line show a strong fixed X-ray energy of 6.7 keV.

Keywords

Flare Stars, Active Eclipsing Binary, Algol, Corona, Stellar Flare, X-Ray, Line Emission

1. Introduction

Stellar properties (temperature, mass, chemical composition, radius and luminosity) of variable flare stars have been observed in the Milky Way Galaxy [1]-[7]. Algol is among the extrinsic variable flare stars (e.g. W Uma, β-Lyrae, RS CVn, By Dra) that have been observed in our Galaxy by different satellites in the X-ray region of the electromagnetic spectrum [8] [9]. Algol is a bright eclipsing binary flare star, believed to be a strong Galactic X-ray energy source, and was discovered in the 1970s as mass-transferring binary system [3] [10] [11]. Moreover, this astrophysical object exhibits stellarspot and it is about ~28.46 parsec away from the Sun. Algol consists of massive (~3.70 $M_{\odot}$) B-type star and its companion less massive (~0.80$M_{\odot}$) K-type star [4]. The B-type star is in its main-sequence, whereas the K-type star is a Roche Lobe sub-giant. The component stars are tidally locked and rotate rapidly around their common barycenter at an inclination of ~81˚ and with orbital periods of about 2.87 days [9] [12] [13] [14]. The convective envelope is one of the characteristics of chromospherically active stars. Algol exhibits strong chromospheres, coronae and stellar coronal activity. The K-star is magnetically active and evolved more than the B-star. This contradicts the theory of stellar evolution in which the more massive star should evolve more than its companion less massive star. Albeit mass transfer mechanism which is an active process in a close binary system resolved this chaos, this suggests that Algol is a chromospherically and coronally active mass-transfer binary system since B-star accretes material/particles from K-star; during rapid rotation [15] [16]. Therefore, the Roche Lobe overflow/Mass transfer mechanisms and stellar magnetic activity through the inner Langrangian point of the binary system explains the coronal X-ray emission [17] [18] [19] and magnetic reconnection of energetic particles in the corona led to the release of sporadic stellar flare [5] [20] [21] [22]. The detectable charged particles in the stellar flare of Algol dissipate enormous energy with a variable X-ray luminosity in the range; 10^{30} - 10^{35} $ergs^{-1}$ [8] [11] [15] [23] [24]. The X-ray spectrum from Algol's stellar flare composed of quiescent and flare phases with a thermal temperature of about ~10^6 K and ~10^7 K respectively and thus, confirms that Algol's X-ray flux varies [14] [16] [17]. There are enormous energies at the flare phase [25] [26], and Satellite (ROSAT, BeppoSAX, Chandra, and XMM-Newton) observations of Algol's stellar flare during the quiescent and the flare epoch in the X-ray regime have revealed the presence of chemical compositions [6] [14] [15] [27]. The geometry of X-ray light curve of Algol obeys the exponential decay law. The evidence of sustained heating during the decay phase of the flare has been revealed, and the corona of the binary system is concentrated onto the polar regions of the K-star [9] [25]. Photo ionization/collisional excitation in the corona of chromospherically active stars, X-ray flare stars and binaries generate 6.7 keV line emission [28] [29] [30] [31]. The observation of 6.7 keV line emission, with an equivalent width range (420 eV - 600 eV), from Algol during the flare phase by GINGA (Japanese for "galaxy" X-ray) satellite has been reported by author of [3], though the X-ray light curve of this observation at different epochs was not explained. Author of [4] and [27] resolved 6.7 keV line emission in stellar flare data of Algol observed by ASCA (Advanced Satellite for Cosmology and Astrophysics) and BeppoSAX satellites, but the equivalent width of the 6.7 keV line emission was not reported.

In this paper, we analyzed the Algol stellar flare data observed with Suzaku satellite. We resolved 6.7 keV line emission from stellar flare of Algol. We vividly explain the X-ray light curve of Algol from epoch to epoch. In Section 2, data acquisition/analysis was discussed. The results are presented in Section 3 whereas Sections 4 & 5 is discussion and conclusion respectively.

2. Data Acquisition/Analysis

The Algol stellar flare photon count/flux data used in this paper was retrieved from the Suzaku Public Archive. The observation of this source was done, in March 8th-10th, 2007 (Obs Id: 401093010), with X-ray Imaging Spectrometer (XIS) on board the Suzaku Satellite with a net exposure time of about 170 kilo seconds. The XIS contains three X-ray charge coupled devices (CCD) camera systems (XIS 0, XIS 1, and XIS 3), with energy resolution of 0.2 - 700 keV. XIS 0 and XIS 3 have front-illuminated (FI) chips while XIS 1 has a back-illuminated (BI) chip. A detailed description of Suzaku satellite is given by author of [32], and [33].

The Suzaku off-line standard version 2.0 software and tools provided in High Energy Astrophysical Software (HEASoft; FTOOLS) version 6.10 software, which run on LINUX. XSELECT and XSPEC software packages which are part of the HEASoft were used. The work directory was prepared and the source's flux was launched into. The XSELECT was used to extract the Algol's spectrum and background spectrum from a circular region of 180 and 100 arc-second radius respectively. A proactive measure was taken during extraction to eliminated X-ray contamination of the apparent (Perseus cluster) and other nearby sources' effect. We also ensured that the circular region of 180 arc-second radius covers about 90% of the Algol's flux, and the background extraction was done within the proximity of the Algol's flux. Each extracted spectrum was saved respectively. The background spectrum was subtracted from the Algol's spectrum, and thereafter, the light curve was generated (see **Figure 1**). The Flexible Image

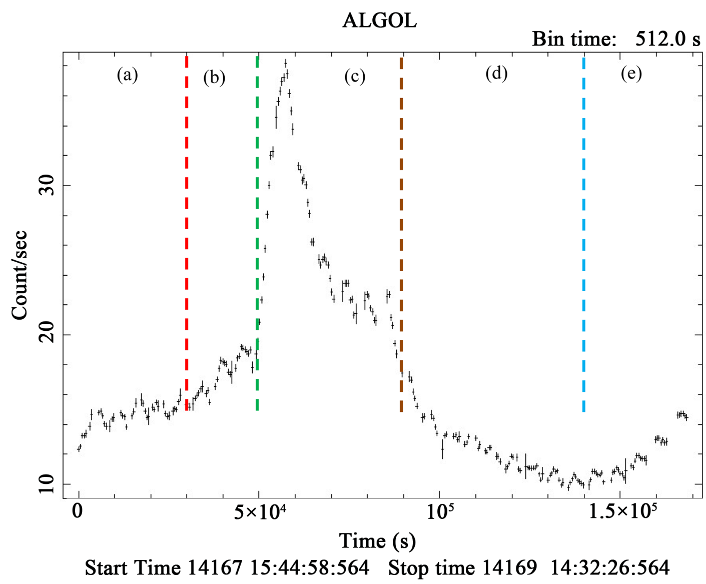

Figure 1. Background subtracted X-ray light-curve of Algol stellar flares.

Transport System Tools (FTOOLS), X-ray imaging spectrometer response matrix file generator (*xisrmf-gene*) and X-ray imaging spectrometer Ancillary response matrix file generator (*xissamrf-gene*) were used to create the Redistribution Matrix File (RMF), and Ancillary Response File (ARF) for the X-ray imaging spectrometer sensors (XIS; 0, 1, and 3) respectively. The X-ray imaging spectrometer sensor 2 has been inactive long ago (see reference therein). We referred XIS1 spectrum as XIS back-illuminated (BI) spectrum. The spectral data of XIS 0, and XIS 3 was merged and we referred it as XIS front illuminated (FI) spectrum. The XIS BI spectrum and XIS FI spectrum analysis were performed using XSPEC version 12.8. Each XIS BI and XIS FI spectrum was modeled using thermal bremsstrahlung model with a Gaussian line.

3. Results

Figure 1 shows the background subtracted X-ray light-curve of the Algol stellar flare. Figure 2 shows the spectra of XIS FI and XIS BI sensors. The peak of XIS FI and XIS BI spectra corresponds to the strong fixed energy at 6.7 keV line emission. Table 1 shows the spectral parameters of the data fitted.

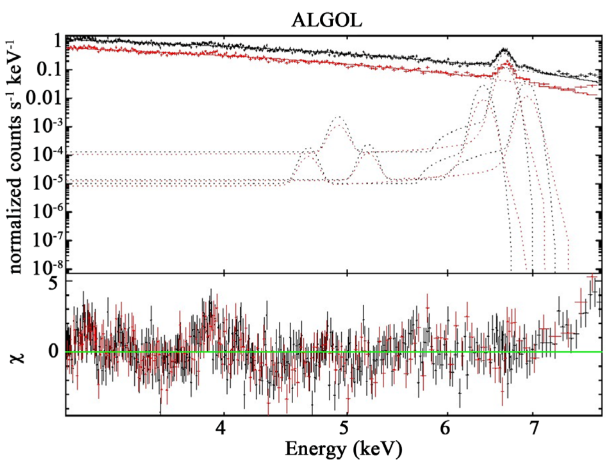

Figure 2. Spectrum of Algol. In the upper panel, the fitted data and the best-fit model are shown by crosses and solid lines respectively. The XIS BI spectrum is the red color while the XIS FI spectrum is the black color. The peak of both spectra shows a strong fixed energy at 6.7 keV line. The cross lines in the lower panel show the ratio of the data to the best-fit model.

Table 1. Algol spectral parameters.

Spectral Parameter	Value	Unit
$E_{6.7}$	6.65 ± 0.01	keV
$EW_{6.7}$	511.00 ± 0.50	eV
F_{count}	(0.175 ± 0.005) × 10^{-3}	Photons $s^{-1} \cdot cm^{-2}$
KT	3.60 ± 0.15	keV
d.o.f	235	-
$R\chi^2$	1.37	-

$E_{6.7}$ = peak energy of the 6.7 keV, $EW_{6.7}$ = equivalent width of 6.7 keV line emission, KT = continuum temperature (energy), d.o.f. = degrees of freedom, ($R\chi^2$) = Reduced Chi Squared value, F_{count} = flux count.

4. Discussion of Results

The X-ray light-curve of the Algol shows a long duration sporadic activity with the typical signature of two-ribbon stellar flare type that obeys exponential decay curve. The magnetic field structure of this stellar flare type is about 10^4 - 10^5 km with complex loop arcades and inter-binary loops [20]. The geometry of X-ray light curve of Algol revealed the starspot evolution during activity-cycle. The X-ray light curve of Algol (**Figure 1**) shows that at time interval between 0 - 30 kiloseconds, uniform brightness of stellar flare was observed and this corresponds to the quiescent phase (region a). The stellar flares brightness rises at an interval of 31 to 49 kiloseconds (region b). The rapid rise in the brightness was observed at the interval of 50 kiloseconds, and the stellar flare attains its peak at 60 kilo seconds. These phases correspond to when X-ray emission from K-star was not eclipsed by its companion. The brightness decreases rapidly at an interval of 61 to 90 kiloseconds (region c). Thereafter, the brightness decays gradually between the intervals of 91 - 140 kilo seconds as B-star occults the X-ray emission from its companion (region d). The stellar flares start to rise again at 141 kilo seconds for another activity-cycle as the component stars rotate rapidly (region d). Therefore, the variations of stellar flare brightness at different interval (epoch) are due to variation in stellar spot during rapid rotation of the component stars. The X-ray emission from Algol is due to magnetic activities and mass transfer/Roche Lobe overflow mechanism. The 6.7 keV line emission is produced in the Algol's corona by photo ionization/collisional excitation processes. The Bremsstrahlung model with a Gaussian line for the 6.7 keV line emission gave a good statistical fits and spectral parameter as shown in **Table 1**. The error in each parameter is estimated at the 90% confidence ranges. The peak of the XIS FI and XIS BI spectra in **Figure 2** represents the strong 6.7 keV line emission. We resolved 6.7 keV line emission during the flare epoch of Algol that is similar to the results of previous spectroscopic studies on Algol [3] [4] [14] [27], but our results show a vivid and clear resolution of 6.7 keV line emission. The 6.7 keV line emission is an indicator of chromospheric activity, and the Algol's energy spectrum is similar to the hard energy spectra of point sources observed in the galactic plane and/or ridge [34] [35] [36] [37]. We obtained equivalent width (EW) of 511 eV of this 6.7 keV line emission which previous research work on Algol [4] [14] [27] was unable to obtain.

5. Conclusion

Suzaku observation of Algol obtained X-ray light curve of the stellar flare that is similar to that obtained by GINGA, ASCA, and XMM-Newton observations [3] [14] [25] [27]. The eruptions in the magnetic field of Algol led to the stellarspot, coronae and stellar flare formations. The strong X-ray energy emission originates from the magnetic corona. The emission measure distribution shape (X-ray light curve) of Algol during quiescent and flare phases is similar to that of some observed flare stars and X-ray binaries that exhibits sporadic flare activities. The 6.7 keV line emission resolved during the flare epoch suggests that Algol is among the Galactic X-ray point sources with strong convective envelope, and high intense chromospheric stellar activity. We are of the view that collection of binary systems like Algol, X-ray flaring stars and chromospherically active binaries (e.g. GT Muscae, Sigma Gem, Sigma CRB, BY Dra, etc.) could account for a large number of galactic fast-transient X-ray sources, and these coronally active binaries could be among the probable sources of 6.7 keV line emission in the galactic ridge.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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