Chandra observations of a young embedded magnetic B star

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Abstract

We report the analyses of the young magnetic B star ρ Oph S1 (hereafter S1) observed twice with the Chandra X-ray observatory for about 100 ksec each. ρ Oph S1 is a highly embedded young star with the magnetosphere, associated with the ρ Ophiuchi cloud core A, and a candidate of young magnetic chemically peculiar(CP) stars. It may fill the gap between pre-main-sequence(PMS) stars and main-sequence(MS) stars and is thus important for studying the evolution of stellar X-ray activity.

With Chandra, the X-ray emission is detected in both observations. The average flux is almost the same between the observations, but, in each observation, it shows significant time variations by a factor of two.Each spectrum is reproduced with an absorbed power law model or thin-thermal plasma model of ~2keV with extreme low metal abundance (less than 0.1 solar). The spectrum in the first observation seems to have an excess above 6 keV, which might correspond to highly ionized iron, whereas the spectrum in the second observation shows an anomalous absorption edge at ~4 keV.

If the X-ray emission is thermal, the log L_X/L_{bol} ratio or the plasma temperature is similar to intermediate mass PMSs than magnetic CP stars (He strong stars). In this case, however, S1 might need to have a mechanism to select elements in the atmosphere, which is generally seen on CP stars. If it is nonthermal, the X-rays might originate from nonthermal bremsstrahlung emission like solar hard X-ray flares, produced by the collision of infalling materials on the surface. A plausible structure of the emitting region is also discussed, including the interpretation of the edge like feature.

1.1 Introduction

Intermediate mass stars do not generally show the magnetic activity. This is explained by the absence of a surface convection zone to generate the solar type dynamo amplification, but following populations among them really have or are thought to have the magnetic field.

Magnetic CP stars ... main-sequence(MS) phase, showing zeeman effect B ~ 10^3 gauss, the dipole magnetosphere

Herbig Ae/Be stars ... pre-main-sequence(PMS) phase, corotating variation of the line emission, suggesting the matter locking on the magnetic field.

Magnetic activity is the origin of the X-ray emission in low mass stars. The above sources have the X-ray emission as well. (ex. Drake et al. 1994, Zinnecker & Preibish 1994, Hamaguchi 2001), but it is not known as whether the emission mechanism has some connection to the magnetic field, nor are the both mechanism the same origin. To address it, we observed ρ Oph S1, which is thought to be between their evolutional phases.

1.2 ρ Oph S1

* B3V star associated with the ρ Oph cloud core A (d~ 120pc, T_{eff} ~ 16,000K, L_{bol}~ $1100L_{solar}$)
* Large magnetosphere (Andre et al. 1988, 1993)
  - nonthermal spectra,
  - circular polarization
* Characteristics of a young star (~ zero age MS)
  - a double peaked SED (Class III)
  - compact HII region
  - heating source of the dark cloud SM1
  - disk dicipation
* X-ray emission
  - log L_X (ergs s^{-1}) ~ 30-31
  - No information about kT, time variation

2. Chandra observations

1st.	April 13, 2000	*exp.* 100ksec
2nd.	May 15, 2000	*exp.* 96ksec

The X-ray emission is detected in both observations. The flux is almost the same.

3. Results

Light Curves

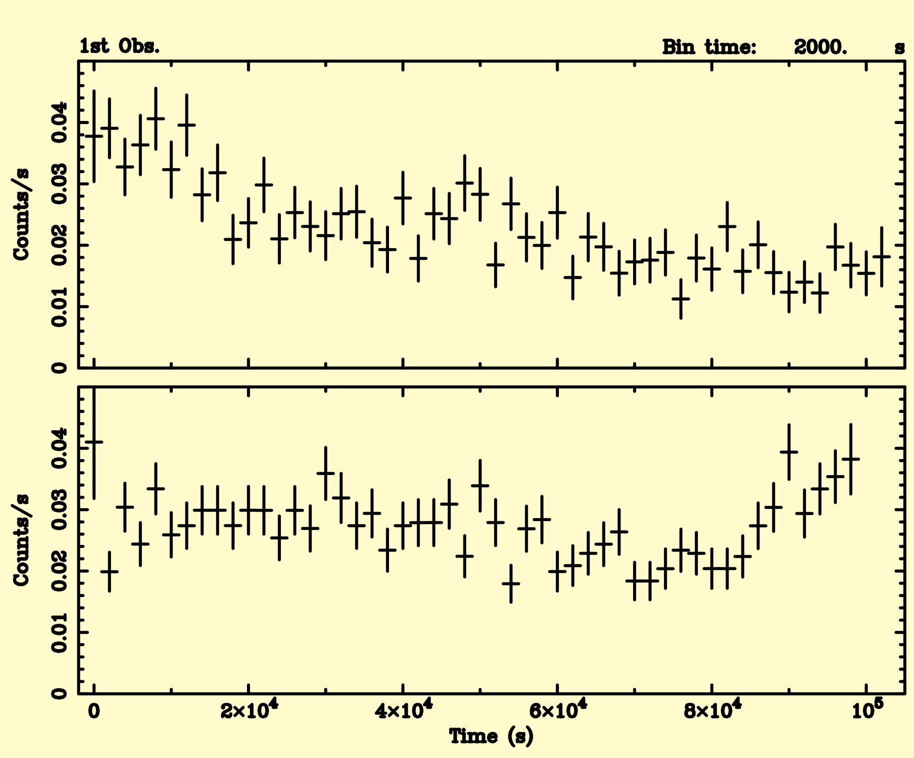

Fig.1 The background subtracted light curve between 0.5 - 9 keV of the 1st(top) and 2nd(bottom) observations. The vertical shows the detector coun rate. Both light curves reject a constant model.

* The X-ray emission is time variable
  - Amplitude: a factor of two
  - Time scale: 20-40ksec.

Spectra

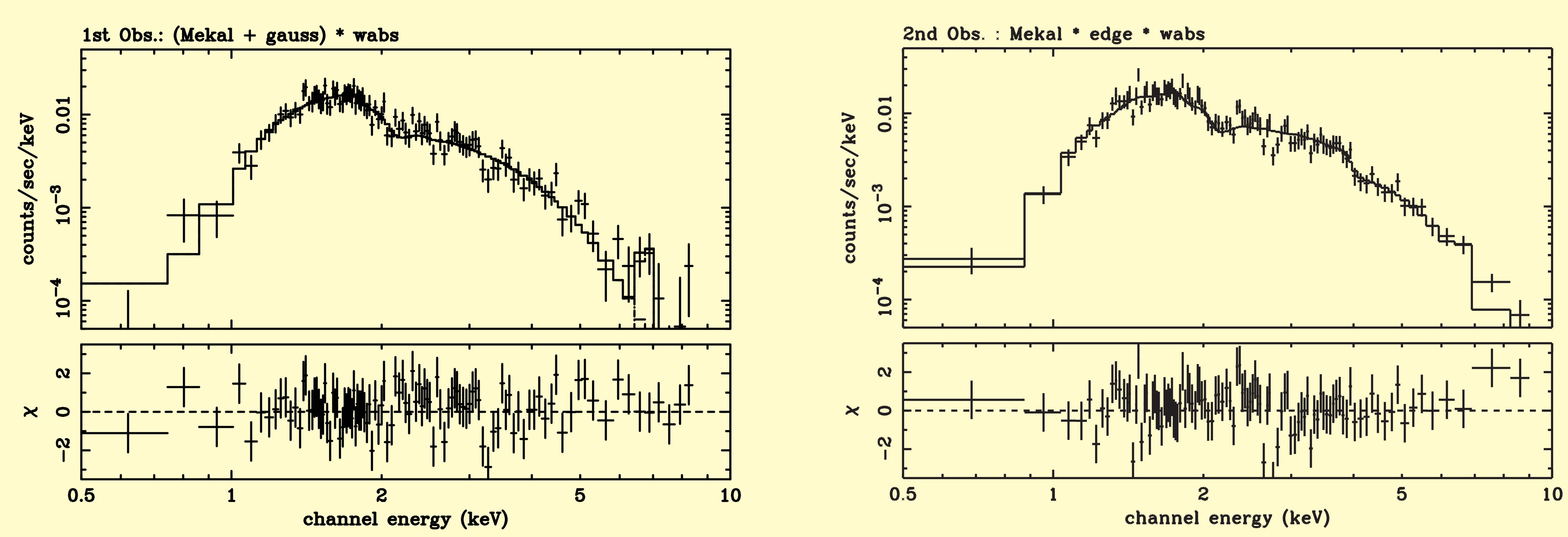

Fig.2 The spectra of the 1st(left) and 2nd(right) observations. The solid line shows the best fit model. The bottom panels show the residual from the best fit model. See Table 1 for the best fit parameters.

* The spectrum of the 1st obs. is reproduced with an absorbed 1T model, but there is an excess at around 6keV.
* The spectrum of the 2nd obs. has a dip feature around 4keV, which requires an edge absorption component on an absorbed 1T model.
* N_H, kT, abundance, $E.M.$ is about the same between both observations.
  - N_H is consistent with A_V
  - The plasma temperature is high (~2keV)
  - The extremely small abundance
* Both spectra are reproduced with an absorbed power law model as well.

Table 1: Fitting result with an absorbed thermal model

Observation		1st	2nd
N_H	[10^{22}cm^2]	1.9 (1.7-2.1)	1.8 (1.6-2.0)
kT	[keV]	1.6 (1.4-1.9)	2.5 (2.1-3.1)
Abundance	[solar]	0.0 (0.0-0.09)	0.14 (0.0-0.28)
$E.M.$	[10^{53}cm^3]	2.8 (2.2-3.5)	1.6 (1.3-1.9)
Line center	[keV]	6.77 (6.5-7.0)	
Edge Energy	[keV]		3.96 (3.8-4.1)
L_X (0.5-10keV)	[10^{30}ergs s^{-1}]	1.9	1.5
χ2/d.o.f		111.3/104	116.5/100

Model: 1st obs.: wabs * (1T Mekal + Gauss)
2nd obs.: wabs * 1T Mekal * edge

4. Discussion

** How similar is S1 to magnetic CP stars or HAeBes?*

CP stars have many subgrroups. The magnetic CP star of the early B type is classified as He rich star. Here we compare S1 with the X-ray property of He rich stars.

	S1	He rich star	HAeBe
log L_X/L_{bol}	-6	-7	-4 ~ -6
kT [keV]	2	<1?	2

S1 is more similar to HAeBe.

** What is the X-ray emission mechanism?*

- If the X-rays are thermal,

The typical length of the plasma (l) is

$l \sim v\Delta T < 5\ 10^{11}$ cm s^{-1}

Here v is a propagation velocity of the plasma heating (5-10 10^7 cm s^{-1}), which assumes the sound speed at 2keV or the wind velocity of the typical B star. ΔT is a variation time scale (20-40ksec).

The plasma density (n) is then,

$n \sim$ sqrt $(E.M./V) \sim$ sqrt $(E.M./l^3) > 10^9$ cm^{-3}

Here $E.M. = n^2 V \sim 3\ 10^{55}$ cm^{-3}. In the magnetic star, the region above $n > 10^9$ cm^{-3} is seen in the stellar surface or the closed magnetosphere.

> The X-ray emission mechanism driven in the closed magnetosphere (the wind-wind collision) cannot heat around to 2keV (Babel & Montmelre 1997).
> The heavy metal selectively conveys above the atmosphere, which suggests the abundance of the closed magnetosphere is large.
-> The X-ray emitting region would be near the stellar surface, but what drives the heating? Magnetic activity? What drives it?

- If the X-rays are nonthermal,

> synchrotoron -> no. Stars do not produce such high energy particles.
> nonthermal bremsstrahlung emission driven by the collsion of infalling materials collides with the stellar surface. This process is seen in solar X-ray flares above 20keV (ex. Sakao et al. 1998)

Infalling materials have to be constantly supplied for S1.
> recycle of the wind material or remained mass accretion?

** What is the features seen in the spectra?*

1. Excess feature above 6keV (1st obs.)

Line center energy - hydrogen or helium like iron
The iron should be ~ 1solar to reproduce the feature, but
- much larger than the other materials and
- iron L line emission is not seen clearly.

2. Edge feature at around 4keV (2nd obs.)

The other models (2T models, line emission) does not reproduce the spectra.
-> The feature might be made by the edge absorption of elements.
Elements corresponding to the edge threshold energy is,

- Ca (Neutral, T < 10^4 K) ... unlikely
  * The abundance must be extremely large (~500solar)
  * CP stars sometimes show the extreme abundance anomalies in rare earth elements, but not for rich elements.
- Ar (XV-XVI, T ~ $10^{6.6}$ K) ... possible?
  * The hydrogen density is not restricted from the spectra, and therefore the abundance may not be large, but larger than the other heavy elements (Mg, S, Si).
  * The absorber and the X-ray emitting plasma coexist in the polar cap?