

# Temporal and Spatial Variation of Synchrotron X-ray Stripes in Tycho's Supernova Remnant

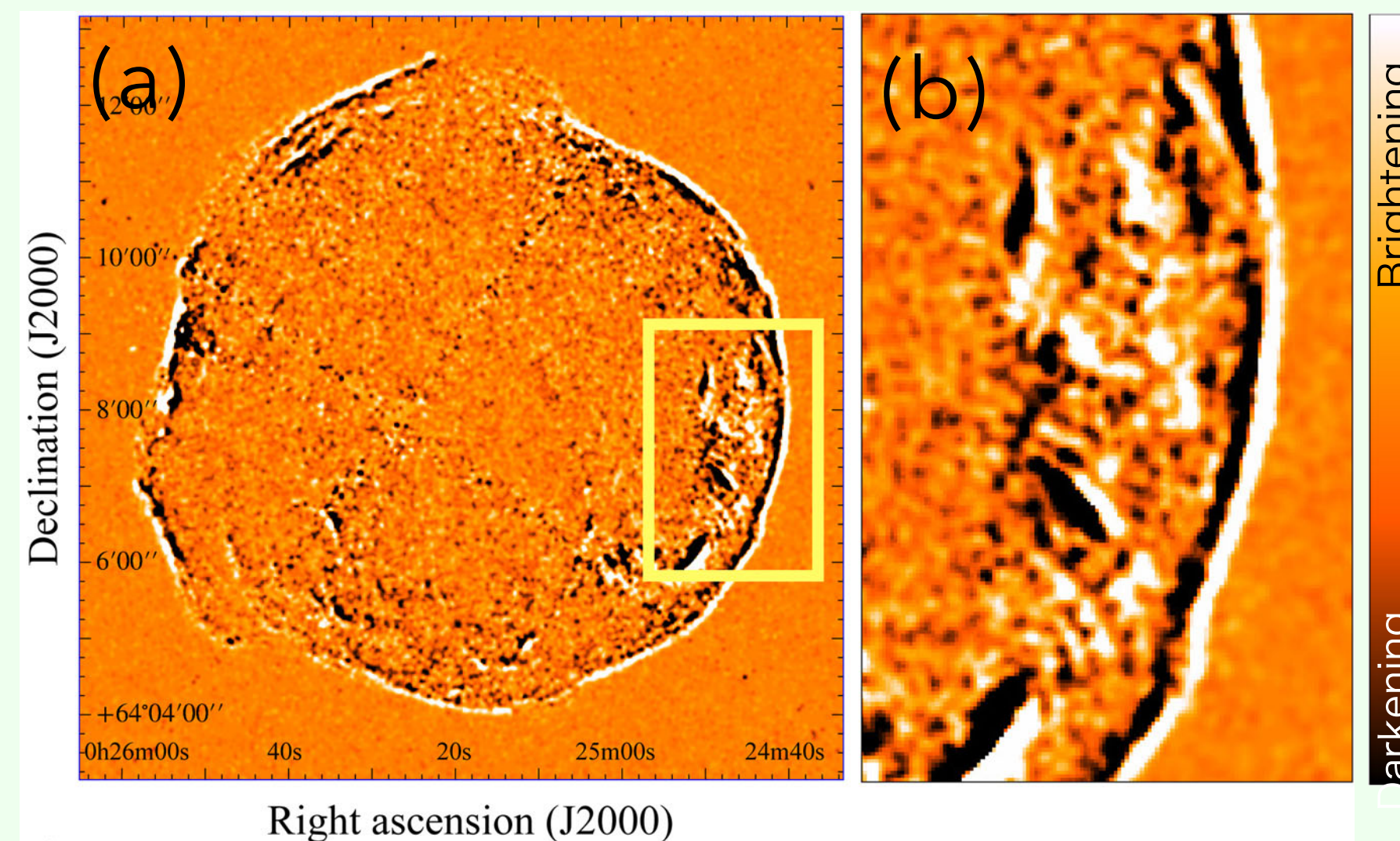
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## Introduction

- Eriksen et al. discovered the synchrotron X-ray **"Stripe"** in Tycho's supernova remnant (SNR) [1]
  - Spacing by  $l_{\text{gap}} \sim 8''$  that corresponds to the gyroradii of PeV protons
  - Some theoretical works propose models [e.g., 2,3]
  - Their theoretical origin is still open.
- We analyzed the stripe with the Chandra data taken in 2003, 2007, 2009, and 2015

## Imaging analysis

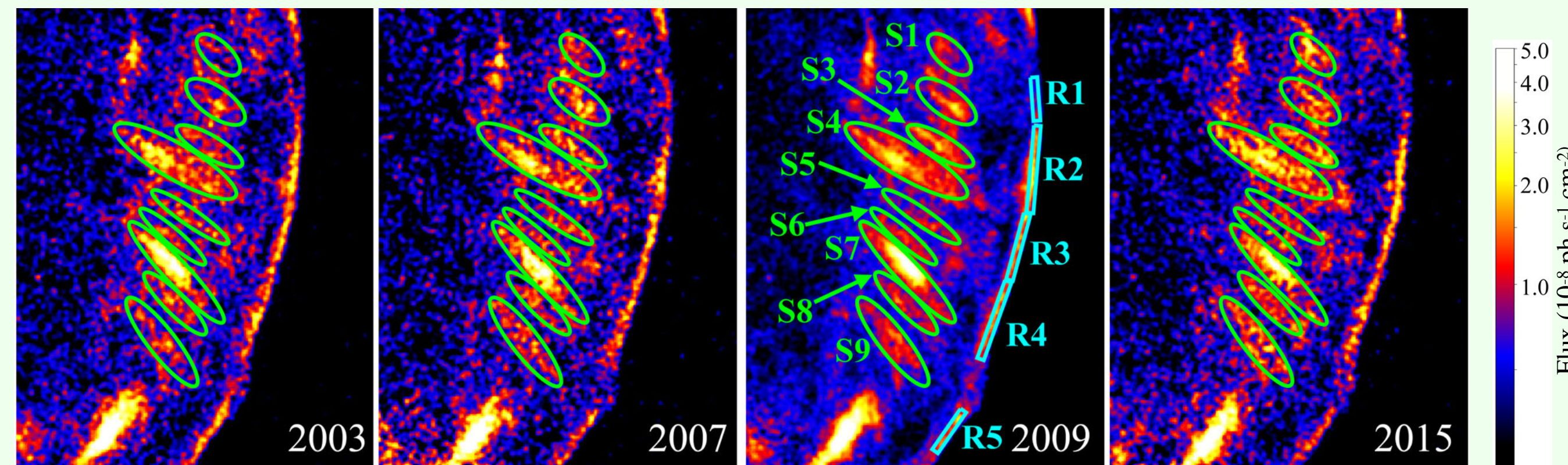


**Figure1.** (a) Difference image the in 4-6 keV band of Tycho between 2003 and 2015. (b) Zoom-in view of the yellow box in (a).

- Figure 1 shows the flux change in Tycho.
- Most of the features show a proper motion by the expansion of the SNR.
- However, **some changes of the stripe feature cannot simply be account for the expansion.**

## Spectral analysis

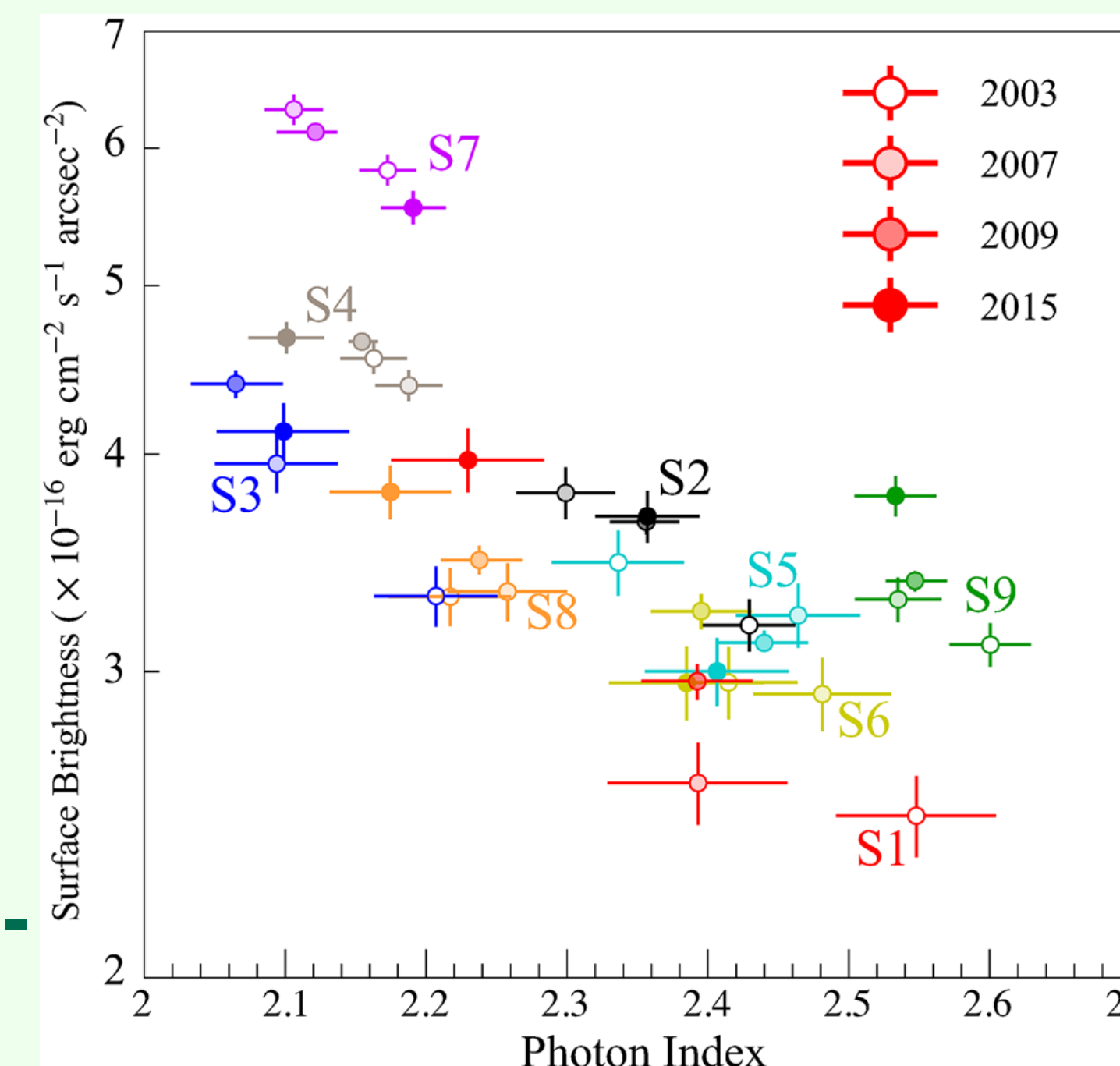
- We analyzed spectra extracted from nine regions (S1-S9 in Fig. 2) of the stripe structure in each year.
- Fitting model
  - Thermal rad.: 2 non-equilibrium ionization
  - Non-thermal rad.: power law ← **Time variable**



**Figure2.** Chandra images in 4-6 keV band taken in 2003, 2007, 2009, and 2015. Green ellipses and cyan boxes are spectral analysis regions.

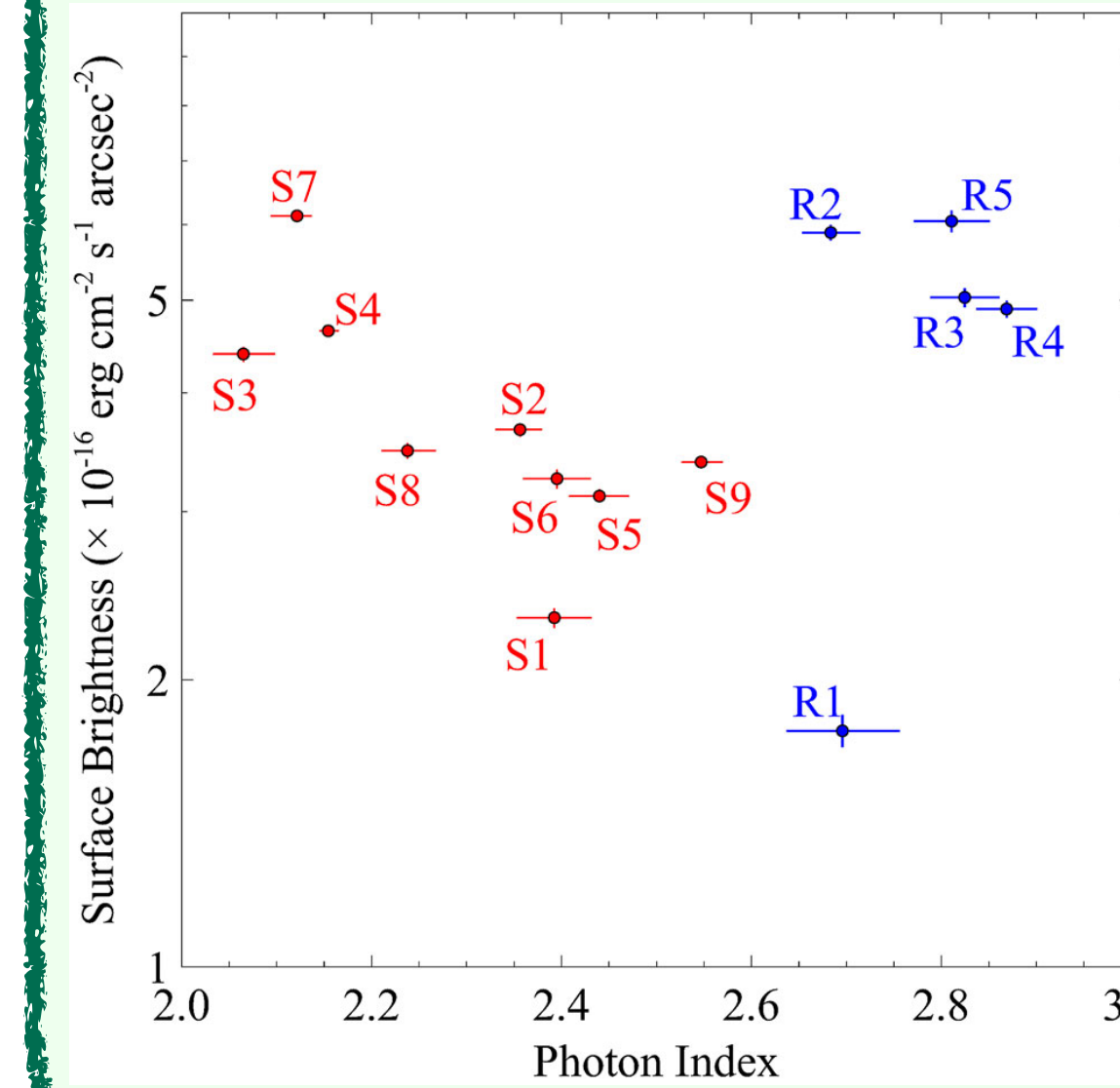
## Time variability of the stripe

- Fig. 3 shows the best-fit parameters of the power-law model
- A significant variation between each stripe and time variabilities in each year
- A strong anti-correlation**



**Figure3.** Relation between surface brightnesses and photon indices in the stripes.

## Comparison with the rim



- The stripes are significantly **harder than the rim.**
- It might be explained by **amplified magnetic fields** and/or **stochastic acceleration** in the stripe.

**Figure4.** Comparison of the relation between the stipe (S1-S9) and the rim (R1-R5)

## Interpretation of the time-variabilities

- Brightening** → increase of relativistic electrons through **acceleration**.
- Acceleration timescale:
 
$$t_{\text{acc}} = 4\eta \left(\frac{\varepsilon}{\text{keV}}\right)^{0.5} \left(\frac{B}{400 \mu\text{G}}\right)^{-1.5} \left(\frac{v_{\text{sh}}}{3400 \text{ km s}^{-1}}\right)^{-2} \text{ yr},$$
- Darkening** → decrease of electrons emitting synchrotron X-rays due to **cooling**
- Cooling timescale:
 
$$t_{\text{syn}} = 4 \left(\frac{\varepsilon}{\text{keV}}\right)^{-0.5} \left(\frac{B}{500 \mu\text{G}}\right)^{-1.5} \text{ yr}.$$
- The magnetic field is amplified to 400-500  $\mu\text{G}$  (?)

## Reference

- [1] K. A. Eriksen et al., 2011, ApJL, 728, L28
- [2] A. M. Bykov et al., 2011, ApJL, 735, L40
- [3] D. Capriorli and A. Spitkovsky, 2013, ApL, 765, L20